Entwicklung einer automatischen Testeinrichtung für Kraft-Weg-Messungen für Erzeugnisse der Automobilindustrie

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HUB- UND KRAFTMESSGERÄT

ZUSAMMENFASSUNG

Die sog. automotive infotainment Systeme sind Ausstattungen der Kfz-Fahrzeuge die mit sehr engen Toleranzen hergestellt werden. Nicht nur die Hardware muss strenge Anforderungen überstehen, sondern auch die Bauteile mit denen der Benutzer interagiert müssen diesen entsprechen. Diese Bauteile sind in diesem Fall die Knopfplatte und die Pinverbindung. Die Knöpfe müssen den haptischen Voraussetzungen entsprechen, die dafür stehen, das Gefühl des Knopfdruckes mit dem der restlichen Schalter des Wagens zu vereinigen. Die Anforderungen der Pinverbindung müssen den ergonomischen und widerstandsfähigen Anforderungen entsprechen.

Diese Charakteristika müssen gemessen werden um sicherzustellen, dass die Prototypen den Voraussetungen entsprechen und damit die Produktion des ganzen infotainment Systems freigeben zu können. Das Ziel dieser Arbeit ist ein solches Gerät zu konstruieren und die Anschaffung der Niederlassung Panasonics in Langen eines solches Systems würde den Prozess der Überprüfung und Änderung der Systeme wesentlich beschleunigen und die Konstruktion erleichtern.

Für die Entwicklung dieses Geräts wurden die Merkmale der beiden Prüfungsarten berücksichtigt, obwohl beide Testarten ganz andere Anforderungen haben. Einerseits braucht man eine sehr genaue Auflösung, Wiederholbarkeit und Genauigkeit für die Prüfung der Knöpfe in einem Kraftbereich von 0 bis 10 N. Die Kräfte, die beim Testen der Pinverbindung vorkommen gehen von -125 N (Zugkraft) bis 450 N (Druckkraft). Außerdem werden bei solchen Prüfverfahren nicht so genaue Sensoren mit so hohen Auflösungen benutzt. Um diese Voraussetzungen einzuhalten wurde ein stabiles und steifes Testgerät mit einem Antrieb, zwei Kraftmessgeräte und einem Wegsensor entwickelt. Einfachheit ist ein Muss wegen der Notwendigkeit einer hohen Stabilität und niedrigen Kosten. Außer der Konstruktion des Geräts wurde auch das Interface mit der Software LabVIEW entwickelt. Die Software zur Kontrolle und Dateneinnahme des Knopfprüfverfahrens ist bereits entwickelt worden und komplett funktionstüchtig, was den Teil der Datenerhaltung des Pinverbindungstests somit als nächste Aufgabe lässt. Obwohl die Wiederholbarkeit des Gerätes hinnehmbar ist, muss dieses von einer spezialisierten Firma zertifiziert werden um es für gültig erklären zu können. Als Ergebnis kann man sagen, dass dieses Gerät eine gute Investition gewesen ist. Panasonic verfügt jetzt über einen low cost Testapparat das der Firma Geld spart, denn die Infotainmentsysteme werden nicht mehr von externen Firmen getestet und Zeit , denn es wird die Prüfung- und Veränderungsprozesse der Prototypen beschleunigen.

FORCE-STROKE TEST DEVICE

SUMMARY

Automotive infotainment systems are automotive equipment manufactured with narrow tolerances. Besides the hardware itself, the components that interact with the user and with the rest of the car have to fulfil strict requirements. These components are the buttons face plate and the pins connector. The buttons must fulfil haptics requirements of force and stroke in order that the feeling of pressing them would be the same as the rest car buttons' feeling. The pins connector must fulfil force requirements in order that ergonomic and resistance characteristics would be achieved.

These characteristics must be measured to verify whether the prototypes are within required tolerances in order to produce the infotainment system model. Developing a test device to check the force and stroke characteristics of infotainment systems is the aim of this project. Having its own force-stroke test device in the Panasonic headquarter in Langen would speed up the process of verification and modification of the infotainment systems prototypes and would simplify the design task.

To develop the suitable test device required, the characteristics of both kind of test have been taken into account. The button test and the pins connector tests have very different requirements. On one hand, the button test requires high resolution, accuracy and repeatability and its range of force is from 0N to 10N. On the other hand, the pins connector tests require applying higher force, from -125N to 450N, being negative for pulling and positive for pushing. Moreover, these kinds of tests do not require sensors resolution and accuracy as high as those for the button test. Taking into account these requirements, a stable and stiff test device with an actuator, two force sensors and a displacement sensor has been developed. The simplicity of the device was a necessity due to the stability and the low cost required. Apart from the design and development of the test device, the application interface has also programmed, using LabVIEW software. The software for controlling and getting the result of the button test has already been developed and is totally functional. However, the software of the pins connector tests will be the next tasks to achieve. Although the repeatability of the test device is acceptable, its accuracy must be tested by a certification company, in order to validate the test device performance. To sum up, this test device has been a good inversion. Panasonic has got a low cost test device with which the company will save money, the infotainment systems will not be tested by an external company, and time, the test device will speed up the verification and modification process of prototypes.

1. INTRODUCTION

During the last years, automotive companies have sought new ways to compete between them giving added value to the car. Nowadays, the car is not only a transport or an indicator of social status, but also seeks to be a place where the occupants feel comfortable and enjoy the interaction between the vehicle and them. This is achieved by taking care of every detail inside the car.

Lately, the fact that all buttons inside the car would have the same feeling when acting on them is becoming more important. This is achieved by standardizing the haptic characteristics of the buttons. Not only are the characteristics of the materials demanded to be similar (roughness, elasticity...), but also, the force and displacement characteristics of the buttons are needed to be equal within tolerances. All components inside the car are not made by the same manufacturer; therefore, each automotive company has its own characteristic standard that the buttons have to fulfil. And are those standards which must also meet the infotainment systems buttons. In addition to the standard of the buttons, each company also developed other standards relating to infotainment systems, such as the characteristic standards of the pins connector.

Panasonic is one of the main manufacturers of infotainment systems and must ensure that their products meet these standards.

1.1. Problem statement

Infotainment systems for the automotive industry are produced with high demands and defined in relevant specifications. In particular, the interfaces to people, including the keys of the keypad, have very exact specifications with a narrow range of tolerances. The aim of these specifications is to obtain a similar tactile sensation for all the keys inside the vehicle regardless from which supplier they are delivered.

Furthermore, the mechanical characteristics of the pins connector (Figure 1-2), at the rear side of the infotainment systems, must meet force and resistance requirements to assemble the infotainment system into the car properly.

Panasonic Automotive Systems Europe GmbH, as a major supplier of car infotainment systems, must meet the requirements of each customer. During the development based on prototypes, it is necessary to carry out measurements to evaluate and verify the service life and that the characteristics values are within tolerances.

Figure 1-1: CDR31 G1 infotainment system front side

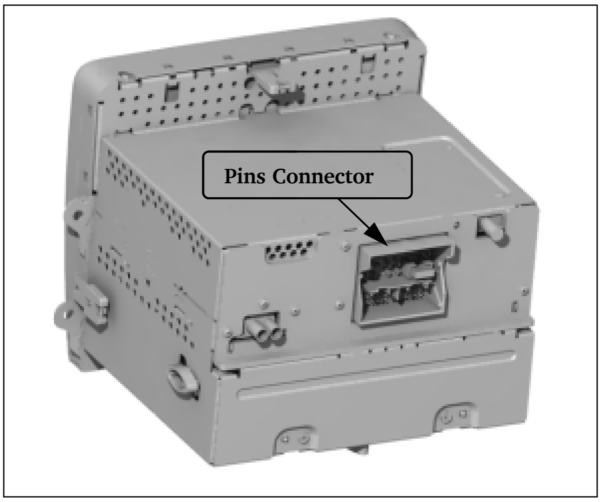


Figure 1-2: CDR31 G1 infotainment system rear side

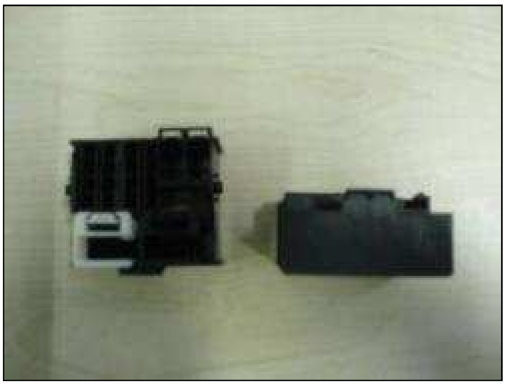


Figure 1-3: Male connectors

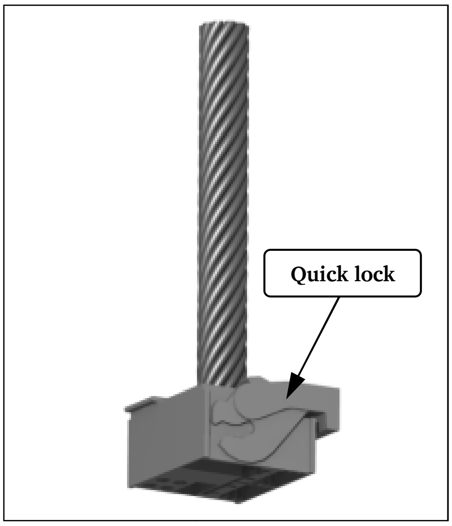


Figure 1-4: Male connector with wires

1.2. Motivation

Panasonic Automotive Systems Europe (PASE) has the main Mechanical Section placed in Langen and its engineers need to check if the designed infotainment system prototypes are within the given tolerances in order to accept the production of the design or, on the contrary, to modify them.

Thus far, there are two possibilities to test the infotainment systems prototypes: send them to an external company or go to the manufacturing headquarter of PASE placed in Czech Republic. In Czech Republic there is a manual force-stroke test device only for testing the buttons characteristics. Both solutions are very expensive and, in order to save money and speed up the process of verification and modification of the prototypes, it was desirable that Langen PASE headquarter owns a test device that could be used *in-situ* by the same engineers who design the infotainment systems.

1.3. Objectives

The aim of this Master Thesis is to design and build a test device and develop the control and data collection software to perform the required tests and determine with reasonable accuracy and repeatability the parameters of force and displacement minimizing the costs. The tests of interest which are going to be performed with this device are:

1. Buttons test: the test device measures the force and displacement of the infotainment system's buttons when they are pressed.
2. Plug test: the test device measures the force needed to plug the male connector (Figure 1-3) into the infotainment system's pins connector.
3. Cable test: the test device measures the lock holding force and the male connector's cable resistance pulling it when its lock is activated.
4. Unplug test: the test device measures the force needed to unplug the male connector out of the infotainment system's pins connector.
5. Pins test: the test device measures the pins resistance of each kind of pin of the infotainment system's pins connector.

The actuation of the test must be performed automatically, controlled by an easy-to-use interface, which will show graphically the results and store the generated data.

To achieve the project's objective, the following tasks must be fulfilled:

- Study of the haptic characteristics and the physiognomy of the infotainment systems already developed.
- Search for suppliers taking into account the requirements of the tests that the device performs.
- Design the structure of the device and the non-commercial parts using CATIA v5 bearing in mind the commercial components selected.
- Order the components.
- Program the device application interface using LabView.
- Assemble the device.
- Install the hardware and the software self-developed.
- Test the device and verify its performance.
- Correlate the data between those obtained from an external verification company and the ones obtained with the test device in order to calibrate it.

2. HAPTIC TECHNOLOGY

2.1. Definition

Haptics is derived from the Greek term *haptios* and describe "something which can be touched"[1]. A touch impression is generated from various factors, such as:

- Texture (rough/smooth, even/uneven)
- Consistency (soft/hard, flexible/in-elastic)
- Form (round/angular, round-off/sharp-edged)
- Mass (large/small, light/heavy, thin/thick)
- Temperature (cold/warm)

For this reason, Haptics means the combined sensation of mechanical, thermal and noci-perception (Fig.2.1).

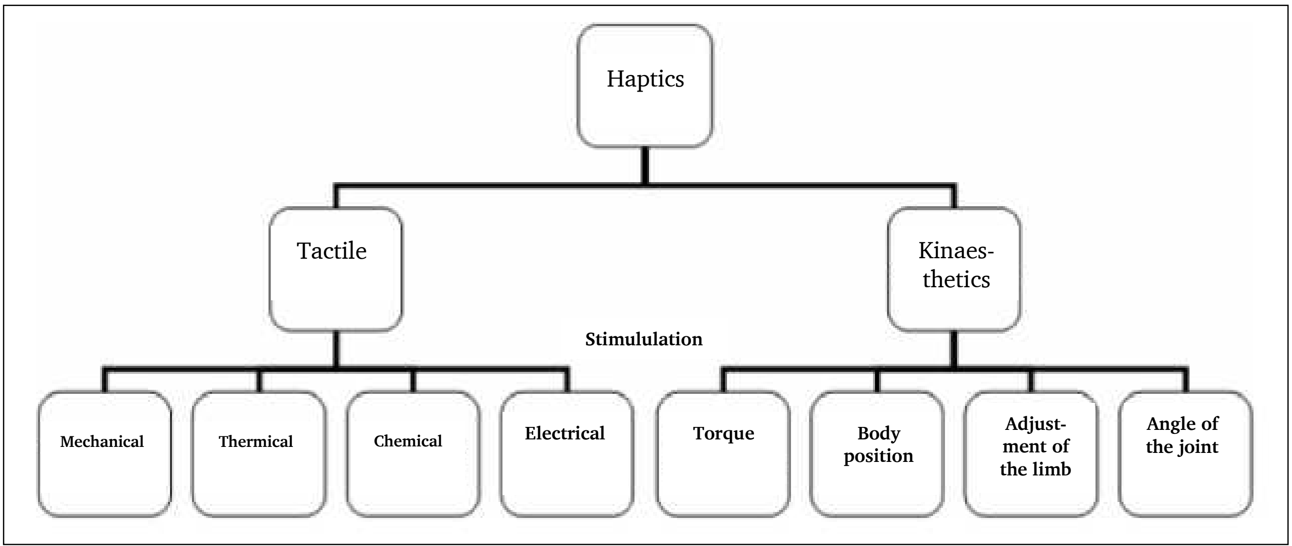


Figure 2-1: Component of the haptics (Modification of Fig.1 from the current ISO 9241-910[2])

According to psychological research into feel, texture and form play the largest role in touch perception when comparing different objects through touching them. Considering that a product is hardly regarded in increasing habitual object use, consistency is highly important as way to distinguish objects. Mass and temperature as distinction criteria play a subordinated role [3].

The haptics technology refers to the assembly of technological interfaces that interact with the user by the sense of touch. Sense of touch is evoked by mechanoreceptors and thermoreceptors of skin, which generate a skin sensation. Although the skin may be our most sensitive organ, it is still not the only haptically relevant one. Additional receptors are located within muscles and joints, which enable us to get an impression of acting forces [1]. Then, we can distinguish between two different perceptions:

- Tactile perception which means the mechanical interaction with the skin. Therefore tactile perception is the sensation of exclusively mechanical interaction. However, it is not exclusively bound to forces or movement.
- Kinaesthetic perception which describes both, actuatory and sensory capabilities of muscles and joints. It refers to their forces, torques, movements, positions and angles. As a result any kinaesthetic interaction has a tactile component.

Whereas tactile perception describes forces (≈ 5 mN..5N) and elongations between skin and object which are low in amplitudes (≈ 1 μm..1 mm) and high in frequencies (≈ 10 Hz..1000Hz), kinaesthetic perception happens at higher forces but with lower dynamics (≈ static..10 Hz). While tactile perception generates similar impressions during passive (e.g. a relative movement between a static finger-tip and a moving surface) and active (e.g. a relative movement between a static surface and a moving finger-tip) movement, kinaesthetic perception is more complex and influenced by additional factors [1].

The definition of the terminology within the context of haptic systems is subject to the current ISO 9241-910 norm [2].

2.2. Haptics interfaces and devices

The sense of touch has numerous functions. The knowledge of functions enables the engineer to formulate demands on the technical systems [1].

A **haptic interface** is a feedback system that generates an output or sensation to the skin and muscles, including a sense of touch, weight and rigidity which can be perceived by applying forces, vibrations, and/or motions to the user [4]. Haptic devices are capable of transmitting elongations, forces and temperature differences and in a few realizations they also stimulate pain receptors [1].

Feel triggers are integrals elements of product design. Product feel triggers are all those tactual sensors that we perceive via our sense of touch [3]. Two different product feel triggers are found: tactile and kinaesthetic triggers. Therefore, the information of a haptic system is transmitted in a tactile and kinaesthetic way.

In the following paragraphs some useful terms and terminology used for haptic systems are described [3].

A **user** (in the context of haptic systems) is a receiver of haptic information. The concept of impedance cannot be applied only to technical systems, but also to a simplified model of the user and his mechanical properties.

A **haptic controller** describes a component of a haptic system for processing haptic information flows and improving transmission.

Haptic interaction decribes the haptic transmission of information. This transmission can be bi- or unidirectional.

The **resolution** of a haptic system refers to the capability to detect a subdivision (spatial or temporal) of an input signal.

A **haptic display** is a haptic device permitting haptic interection, whereby the transmitted information is subject to change. The tactile display that stimulates skin sensation is a well-known technology. A sense of vibration is relatively easy to produce, and a good deal of work has been done using vibration displays. The micro-pin array is also used for tactile displays [5].

A **haptic manipulator** is a system interacting mechanically with objects whereby continuously information about positions in space and torques of the interaction is acquired.

A **telemanipulation system** refers to a system enabling a spatial separated haptic interaction with a real physical object.

A **haptic assistive system** is a system adding haptic information to a natural interaction. For this purpose object or interaction properties are measured via a sensor and used to add valuable information in the interaction path.

A **haptic simulator** is a system enabling interaction with a virtual object. They can be found in serious training applications, e.g. for surgeons, as well as in gaming application for private use (see also section 2.3).

Active haptic devices are systems requiring an external energy source for the display of haptic information. Usually, these are at least haptic displays.

Passive haptic devices, on the contrary, are systems transmitting haptics information solely by their shape.

2.3. Applications

Haptics is an emergent technology that since a pair of decades has been promisingly developed. Here are listed some of the most relevant applications of haptic devices:

Teleoperators and simulators

Teleoperators are remote controlled robotic tools, and when contact forces are reproduced to the operator, it is called "haptic teleoperation". The first electrically actuated teleoperators were built in the 1950s at the Argonne National Laboratory in the United States, by Raymond Goertz, to remotely handle radioactive substances display [3].

Haptic simulators are currently used in medical simulators and flight simulators for pilot training [6].

Computer and video games

Some haptic interfaces are common in the form of game controllers, in particular of joysticks and steering wheels.

In 2007, Novint released the Falcon, the first consumer 3D touch device with high resolution three-dimensional force feedback, allowing the haptic simulation of objects, textures, recoil, momentum, physical presence of objects in games.

Mobile consumer technologies

Tactile haptic feedback is becoming common in mobile phones in order to make the ring tone haptically perceptible or when the tactile screen is pressed. In most cases this takes the form of vibration response to touch.

A vibration–motor is a haptic device addressing tactile perception. It is a pure form of a haptic display, or more precisely a purely tactile display [3].

Medicine

Various haptic interfaces for medical simulation may prove especially useful for training of minimally invasive procedures (laparoscopy/interventional radiology) [7] and remote surgery using teleoperators. Haptic interfaces are also used in Rehabilitation robotics.

Haptics in virtual reality

Haptics are gaining widespread acceptance as a key part of virtual reality systems, adding the sense of touch to previously visual-only solutions. These systems are also being developed to use haptic interfaces for 3D modelling [6].

Robotics

Humanoid robotic systems require a sense of touch as well as haptic depth sensibility in order to move, work and manipulate in typical human everyday environments [5].

Actuators

Haptics is enabled by actuators that apply the forces to the skin for touch feedback. The actuator provides mechanical motion in response to an electrical stimulus. Next generation haptic actuator technologies include electroactive polymers, piezoelectric, and electrostatic surface actuation [8].

HapticWalker

The HapticWalker is a novel generic haptic walking interface, which is based on the principle of programmable footplates with permanent foot machine contact. It comprises a specially developed robot kinematics, and is equipped with highly dynamic drives in order to be able to perform natural walking movements [5].

Future applications

Future applications of haptic technology cover a wide spectrum of human interaction with technology. Some current research focuses on tactile interaction with holograms and distant objects, which, if successful may result in applications and advancements in gaming, movies, manufacturing, medical, and other industries. The medical industry will also gain from virtual and telepresence surgeries, providing new options for medical care [5].

Although research into haptic interface is growing rapidly, its methods are still in a preliminary state.

2.4. Haptics in the automotive industry

A very flourish application of haptics technology is in the automotive industry.

Haptics research pursues three objectives in the automotive industry:

- Ensure ergonomic, reliable operation and driving of the vehicle
- Provide the vehicle with a top-quality, harmonious overall design
- Provide a detailed specification of customer requirements for development of the vehicle components involved.

A vehicle forms a suitable equipped living environment. This requires these components to be manufactured to a high level of sophistication. Taking as an example an ashtray, its design should ensure that the ashtray opens quietly and with an even movement. The mechanisms have to fulfil specific requirements to create opening and closing actions that feel pleasant for the customer [5].

Suitable function units are selected on the basis of the customer’s view.

One frequent subject of haptics studies is push–push switches, i.e., press able switches which return to their original position. In the vehicle they are used, for example, to activate the air-conditioning system or to call up stored radio stations [5].

In the research of push-push switches, for instance, a high number of different factors influence on the haptic experience and are taken into consideration.

In the case of a switch, size and shape special care must be taken to ensure ergonomic design, allowing optimum. The material and surface quality also determine the perception of a switch when it is touched and operated [5].

The force-travel characteristic chart (Figure 2-2) describes the force which has to be applied between touching the experience appeal of a switch. This force-travel characteristic is typically non-linear and can be divided into different sections (upper curve represented in Figure 2-2). A usually convex rise in actuating force is followed by a drop in force (snap). On the follow-up journey the force rises again. The lower curve in Figure 2-2 illustrates the force-travel behaviour after releasing the switch [5].

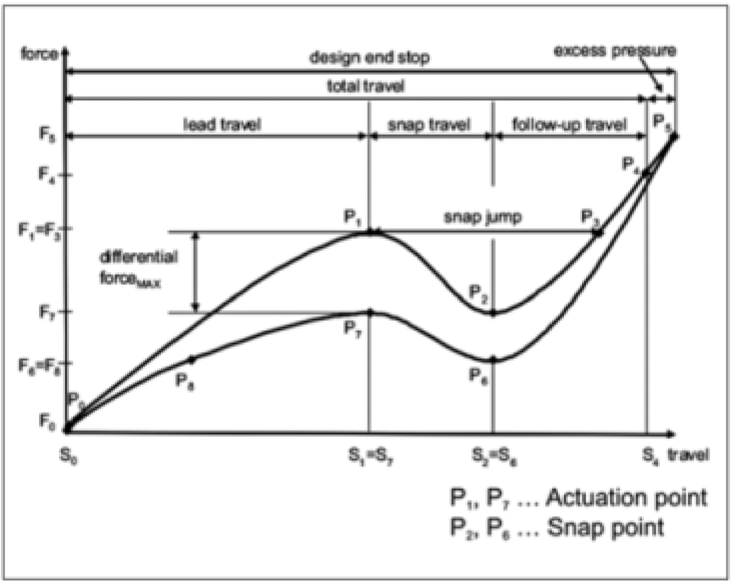


Figure 2-2: Force-travel characteristic [5]

From the characteristic chart it is possible to obtain various forces and travel parameters that describe the haptics of the switch in physical terms.

2.5. Haptic experimental approaches

For haptic studies an experimental approach is normally considered which allows the comparison of a number of variants within the scope of a factorial trial design. In the following, two experimental procedures are described.

Function components

Various versions of a component function can be created in the specified installation space with different opening movements, forces and kinematics. The variants are subjectively analysed through comparison by a representative group of people using quality-based assessment criteria.

In this example, several variants will be tested. A quality assessment is going to be made based on the criteria noise, perceived mechanical action and force [5]:

- *Noise* refers to the operation noise, i.e., the acoustic feedback from a closing movement. Depending on the range of noise produced, this acoustic feedback may be perceived as positive or negative. In addition, acoustic feedback frequently leads to a haptic perception. A defined click noise at the beginning of the operation of a component in combination with haptic feedback in the form of a resistance point, for example, can produce an overall high-quality operating feel.
- *Perceived mechanical action* means the running properties of a mechanism when operated.
- *Force* refers to the level of force applied to operate the component. All possible users can easily apply the required force when the function component is at a given position.

Switch haptics developement

Several variants are characteristically compared with each other to determine the optimum switch actuation haptics for a specific object.

In order to define a variant, the achievement of a maximum constancy of influencing factors which are not the direct subject of the haptic investigation (e.g., switch size or surface design) should be taken into consideration.

The force-travel characteristic of the variants is varied as systematically as possible in order to clearly attribute differences in subjective assessment (dependent variable) to physical features (independent variable) and ensure internal validity [5].

Taking only decisions about haptics, a valuable advice is to mask the sounds to avoid confusion between the haptics and acoustics of the controls.

As explained in the previous section (See section 2.4), force-travel charts can be used to derive a large number of parameters which can be varied by experiments, making it necessary to focus on a small number of crucial variables. The important variables are known from previous process steps.

A typical haptics experiment would, for example, vary two influencing factors in three stages separately from one another, which would result in a total of nine variants being investigated (e.g., three conditions for lead travel *x* three conditions for snap travel) [5]. Figure 2-3 shows systematic variation of lead travel.

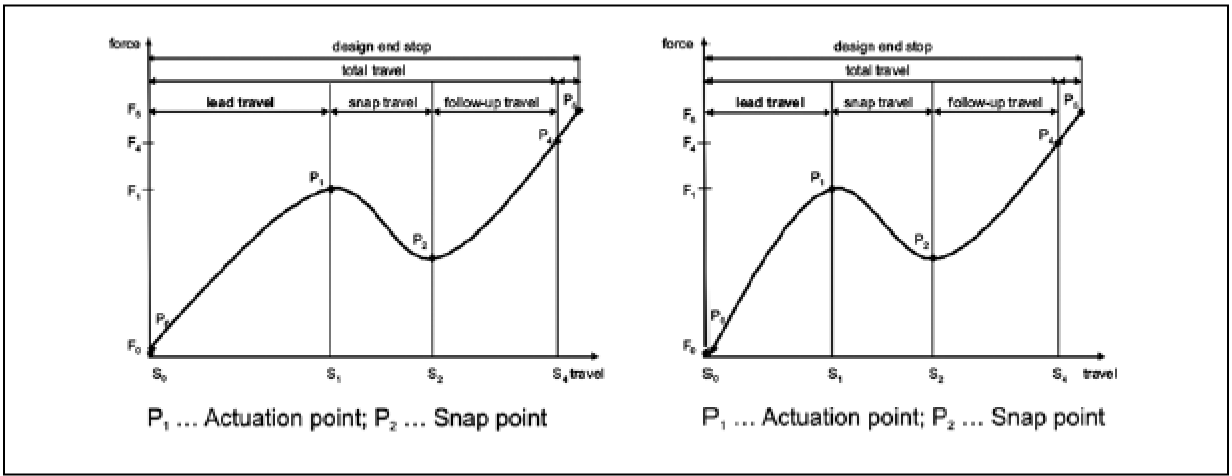


Figure 2-3: Force-travel characteristic: modification of lead travel twice [5]

Paired comparison of always two haptic variants and statistics make it possible to reveal even minimal differences. If the number of variants being evaluated is very high, they are presented one after the other and evaluated individually. Repeated presentation of the various switch types increases the quality of testing [5].

3. METHODOLOGY

The methodology for developing this project is based on the method proposed by Pahl and Beitz and defined at the Guidelines VDI 2221 [9] and VDI 2222 [10, 11], all of them summarised at the book “Engineering Design” [12] (See Figure 3-1). From this model, the four main phases for designing a device are taken: task clarification, conceptual design, detail design and production and operation documents preparation. To these four phases, the manufacturing process, the application interface development and the performance evaluation has been added, in order to do a right monitoring of the test device construction and verify the proper performance.

In the initial phase of **task clarification**, the study of the physiognomy and mechanical characteristics of the latest infotainment systems of each customer and the study of the requirements of each customer have been developed. Furthermore, the state of the art, researching information about haptics, and the project schedule have been performed.

In the **conceptual design** phase, the black-box and the function structures have been developed which allowed creating the morphological solution box, configuring some concepts and variants and selecting the main solution.

Afterwards, the **detail design of the final solution** has been developed, selecting the suitable materials and components, performing some structural and mechanical calculation and modelling the final concept using CATIA v.5 in order to create the definitive layouts.

After checking for errors, detail drawings, parts lists and production and assembly instructions have been created with the aim of ordering the commercial components and manufacturing the non-commercial parts, at the manufacturing process phase. When all components were received, the device was assembled.

Once the final solution was defined, the **software development** phase began. Before starting programming the function using LabView, the control parameters and the operation procedure were defined. After programming the main safety functions, the software was implemented to the device in order to check the operating performance, solve errors and improve the application interface.

Finally, the **device performance was verified** by means a test evaluation protocol with the aim of fulfilling properly product documentation.

The shows Figure 3-2 the complete methodology from which the test device was developed.

See the Schedule of the project at the Appendix A.

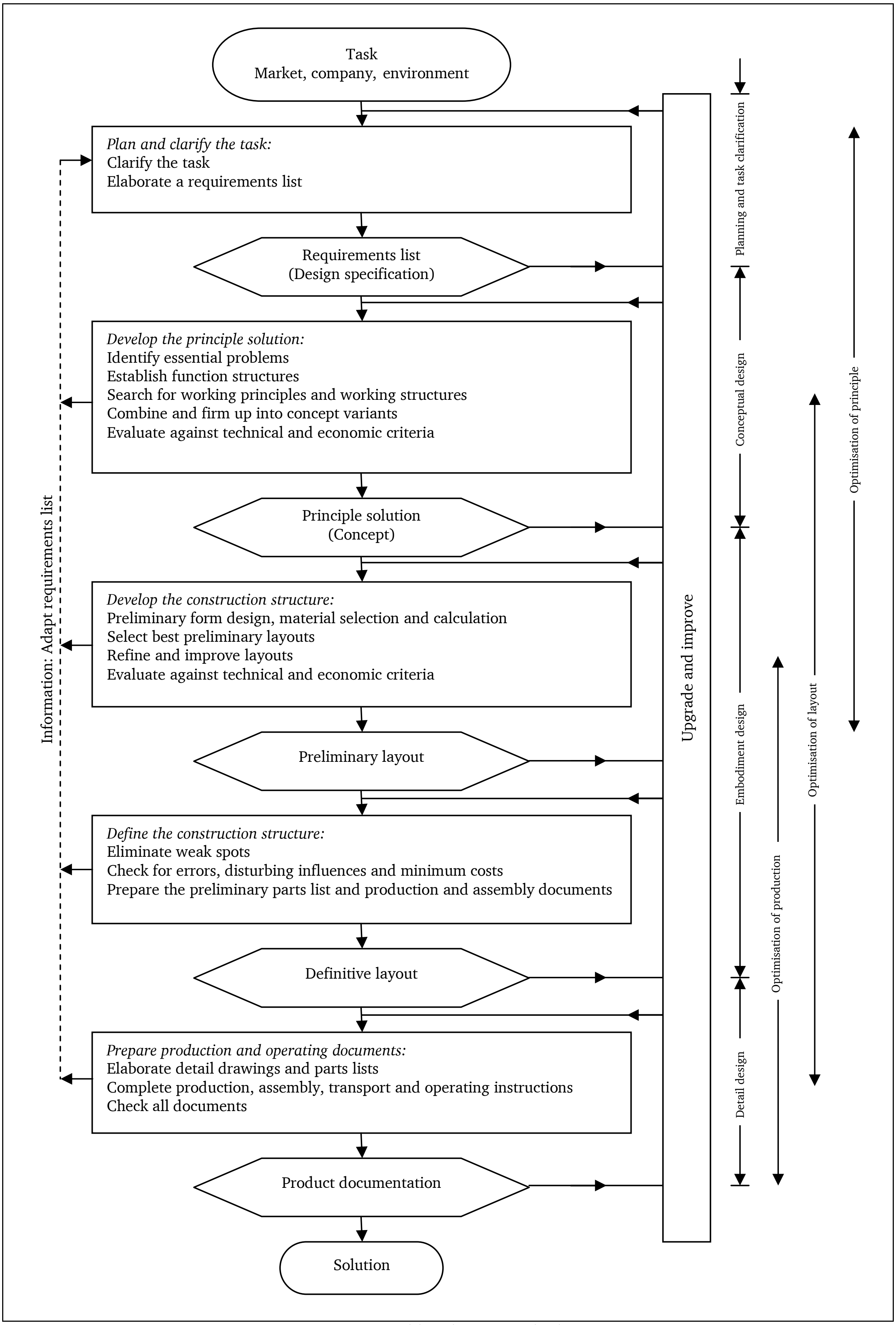


Figure 3-1: Pahl and Beitz method [12]

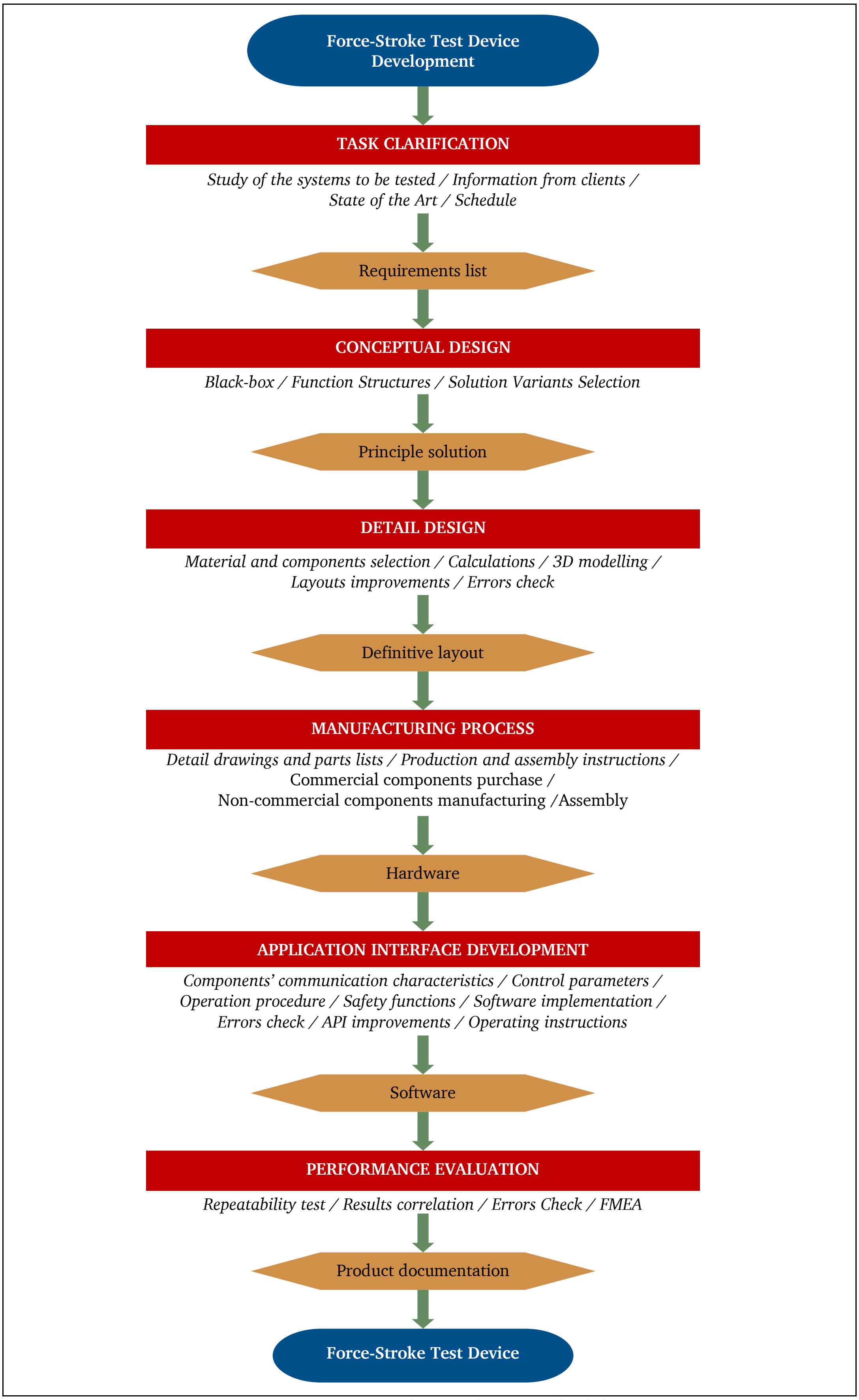


Figure 3-2: Force-Stroke test device methodology

4. DESIGN

4.1. Requirements list

The requirements list is a compilation of two kinds of requirements, the ones from the automotive customers, who define the characteristics that the infotainment systems have to fulfil, and the ones from PASE, who define the general characteristics of the test device.

This list plays a very important role in order to succeed with the aim of any project.

First of all, the test device was only required for performing the button test, but after some weeks, the plug, unplug and pins tests were added to the requirements list. These last tests differ very much from the button test and the initial design concept had to be changed. Unexpectedly, also some more requirements about the procedure of the plug and unplug test were modified and a cable test was added in the last months of the project. These changes caused some modifications of the dimensions of the final design's parts.

The tests that the force-stroke test device is going to perform and a summary of the requirements of each test are described below:

4.1.1. Buttons test

The force-stroke characteristic of the infotainment system buttons is non-linear. Usually convex rise in actuating force, until the actuation point (1), is followed by a drop in force, until the snap point (2). On the follow-up journey the force rises again. The lower curve in Figure 4-1 illustrates the force-stroke behaviour after releasing the switch.

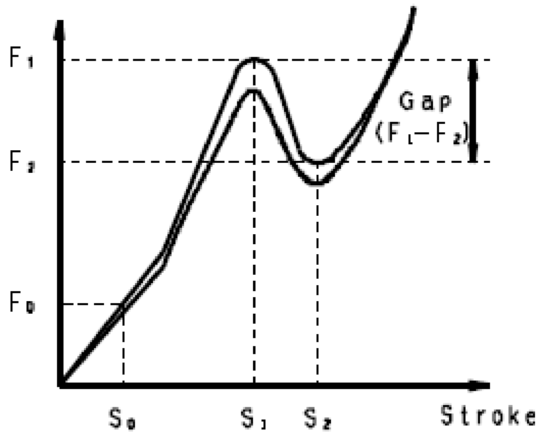


Figure 4-1: Buttons force-stroke characteristic [13]

For this test, the characteristics of force and stroke of the actuation point and the snap point of all infotainment system buttons are verified to be within tolerances, once the buttons are pushed.

Each automotive company requires checking certain characteristics. The most common characteristics to be checked are F1, S2 and SNAP ((F1-F2)/F1). This checkout is required, for example, by Daimler and Porsche.

Other companies, such as Audi, require checking other characteristics. The characteristics that Audi requires to be checked are the operating force (F1), the drop in force at the switching point (F1-F2), the difference of stroke at the drop in force (S2-S1), the contact travel (S1) and also a linear force increase between 0mm to the switching point.

The characteristic curve of the switches that use the infotainment system buttons is the one shown at the Figure 4-1. In order to achieve a linear force increase, it is necessary to add a thin metal plate to the switching mechanism and the force-stroke characteristic curve shown in the Figure 4-2 will be obtained.

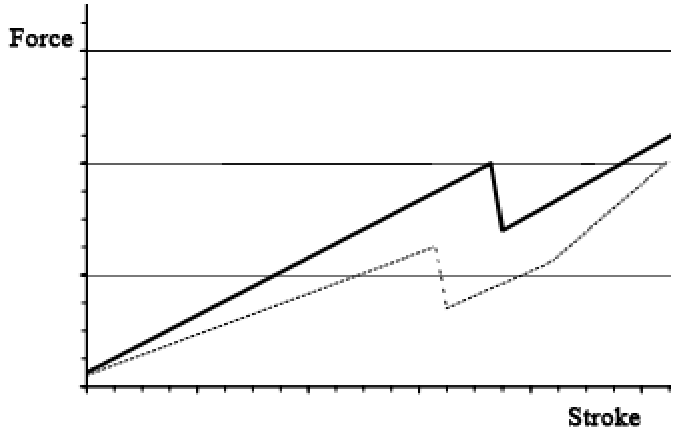


Figure 4-2: Audi buttons force-stroke characteristic [14]

In order to check the shape of the force-stroke characteristic, it is required that the application interface shows this graph.

The range of force and stroke of this test are about 10N and 1,5mm approximately, depending on the customer.

Haptics technology is widely developed in the chapter 2.

The requirements of this test are the following:

- Force range: 0 – 10N
- Force resolution: 0,01N
- Max. button stroke: 1,5mm
- Displacement resolution: 0,01mm
- Show the force-stroke diagram of the button to check it (the customer could demand a linear force increase).
- Check that the maximum and minimum force and the stroke at minimum force are within the given tolerances.

Figure 4-3: Button test

4.1.2. Pins connector tests

There are four different tests related to the pins connector (See Figure 1-2).

4.1.2.1. Plug test

For this test, the force needed to plug the male connector into the pins connector is checked.
The procedure of this test is the following (See Figure 4-4):

1. Let the male connector without wires (See Figure 1-3) on the pins connector (See Figure 1-2)
2. Push the male connector inside the pins connector increasing slowly the force applied until 100N.
3. Maintain the force for 10s
4. Push the male connector increasing the force until 150N
5. Reduce the force moving the actuator head back to its initial position

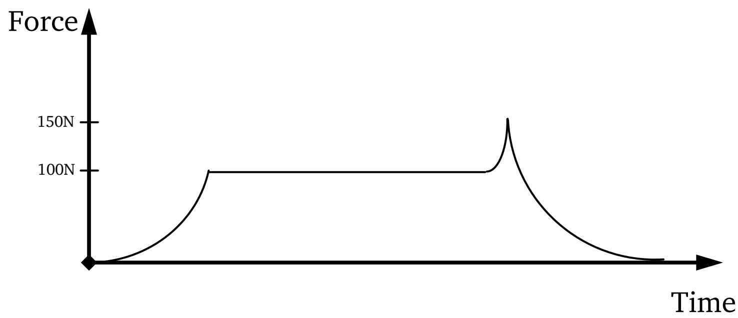


Figure 4-4: Force-time plug test characteristic

The graph curves are not linear because it is easier to control the actuator defining a constant velocity. As a result, the displacement-time curve is linear but the force-time curve is exponential with a large increase in force when the part that receives the force could not move.

The force range for this test is 0-150N.

The evaluation criteria are the following:

a) The plug must be securely locked at $F<F_{plug}$ (100N)
b) Visual evaluation of the connectors
c) Evaluation of the Force-Stroke diagram to check that the total connection has been achieved before reaching the 100N

The requirements of this test are the following:

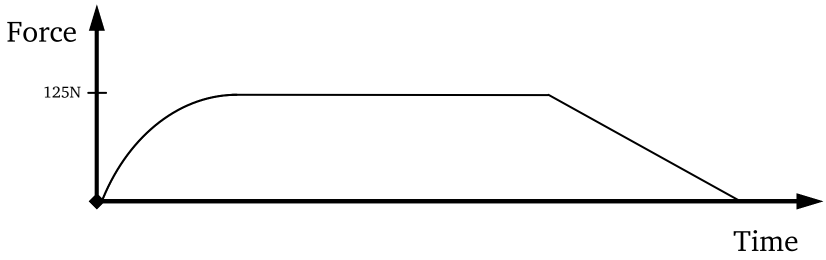
- Force range: 0-150N
- Force resolution: 0,1N
- Max. male connector displacement: 20mm
- Displacement resolution: 0.01mm
- Show the force-stroke diagram in order to check that the connection has succeeded in one stage.
- Check that the force required for plugging the connector is within the given tolerances.

Figure 4-5: Plug test

4.1.2.2. Cable test

For this test, the resistance of the cable and of the quick lock (See Figure 1-4) are checked.
The procedure of this test is the following (See Figure 4-6):

1. The male connector with wires must be inside the pins connector fixed with the quick lock
2. Fix the wires at 10cm length from the male connector
3. Pull the wires up to 125N
4. Maintain the force for 20s
5. Reduce the force 10N/s until 0N



The force range of this test is 0-125N.
To check the results, a visual evaluation of the cables and the quick lock has to be performed.

The requirements of this test are the following:

- Force range: 0-125N
- Force resolution: 0,1N
- Show the force-time diagram
- Check that the wires have resisted the maximum force.

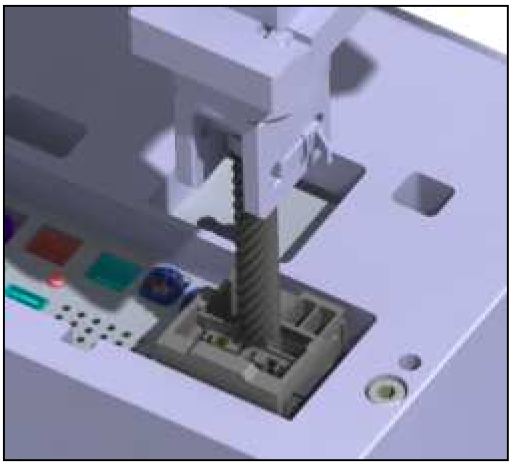


Figure 4-7: Cable and unplug test

4.1.2.3. Unplug test

For this test, the force needed to unplug the male connector out of the pins connector is checked.
The procedure of this test is the following (See Figure 4-8):

1. The male connector with wires must be inside the pins connector and the quick lock must be released
2. Fix the wires at 10cm length from the male connector
3. Pull the wires until the male connector is unpluged

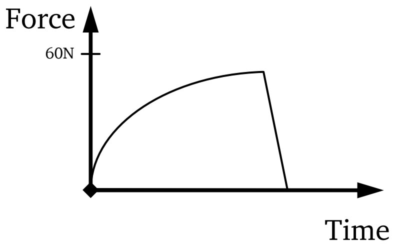


Figure 4-8: Force-time unplug test characteristic

The force range of this test is 0-100N.
The evaluation criteria are the following:

a) Pull out force < 60N
b) Visual evaluation of the cable and the connectors

The requirements of this test are the following:

- Force range: 0-100N
- Force resolution: 0,1N
- Max. male connector displacement: 20mm
- Displacement resolution: 0.01mm
- Show the force-stroke diagram
- Check that the unplug force is within the given tolerances.

4.1.2.4. Pins tests

For this test the resistance of each kind of pins of the pins connector is checked.
The procedure of this test is the following (See Figure 4-9 and Figure 4-10):

1. Push the pin. Increase slowly the force up to 450N
2. Maintain the force for 10s
3. Reduce the force until 0N

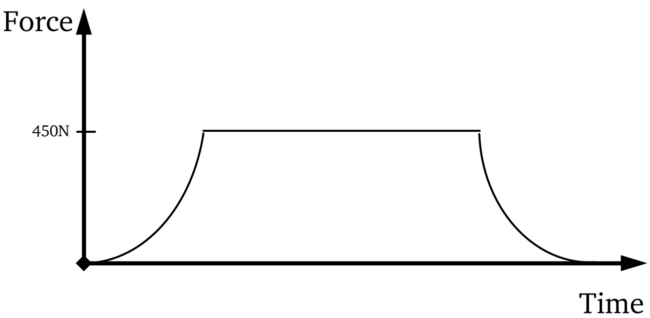


Figure 4-9: Force-time pins non-destructive test

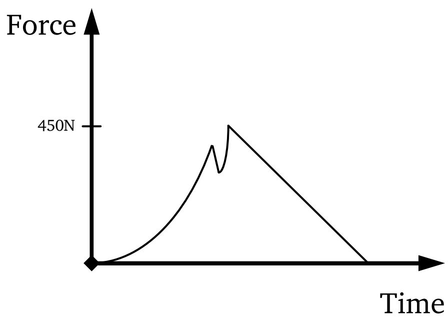


Figure 4-10: Force-time pins destructive test

The force range of this test is 0-450N.
The evaluation criteria are the following:

a) The pins must resist up to 450N force
b) Visual evaluation of the pins

The requirements of this test are the following:

- Force range: 0-450N
- Force resolution: 0,1N
- Max. pin stroke: 0,7mm
- Displacement resolution: 0.01mm
- Show the force-stroke diagram
- Check the resistance of the pins (the pins, the welds and the support points should not have been broken).
- Check that the deformations of the pins are within the given tolerances.

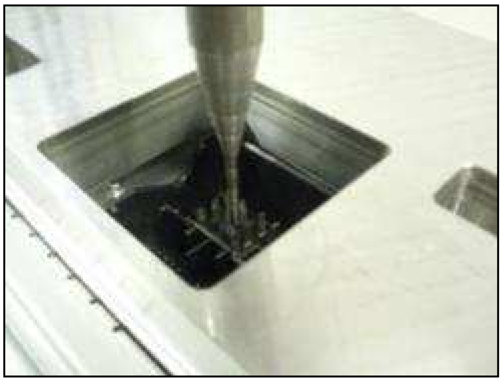


Figure 4-11: Pins test

The above mentioned requirements will be included in the requirements list (Table 4-1). The list of requirements provides the individual items with a serial number and identifies the items either as demands (D) or wishes (W). Despite the demanded requirements must be met under all circumstances, wishes requirements only should be taken into consideration. These requirements are divided into suitable categories, such as geometry, kinematics, dynamics, costs, etc. All occurring requirements are described and quantified.

PASE Jose Romero		Requirements list for a force-stroke test device		Page 1
Serial Nr.	**Categories**	**D/ W**	**Requirements**	**Quantification**
1	Geometry	D	Working place big enough to move freely all infotainment systems models and test all of their buttons	
2		D	Actuator and displacement sensor stroke high enough to sweep all infotainment systems heights	
3		D	Range of infotainment systems height	180-215
4		D	Range of infotainment systems width	180-225
5		D	Range of infotainment systems depth	57-165
6		W	Test device volume	$<1m^3$
7	Kinematics	D	Precise positioning of the test sample	
8		D	Automatic movement to perform the tests	
9		D	Displacement measurement	
10		D	Low speed working actuation	~0,1mm/s
11		D	Displacement resolution	≤0.01mm
12		W	Displacement accuracy	≤±0.05mm
13		W	Displacement repeatability	≤±0.05mm
14		W	Automatic positioning of the infotainment system	
15	Statics	D	Stable, stiff and robust structure	
16		D	Stable and rigid infotainment system fixation	
17		D	Polyvalent fixation for all infotainment system models	
18	Forces	D	Force range	0-500N
19		D	Smooth application of the force	
20		D	Applied force measurement	
21		D	Normal force applied	
22		D	Force resolution	≤0.01N
23		W	Force accuracy	≤±0.1N
24		W	Force repeatability	≤±0.1N
25	Energy	W	Electrical primary energy	220V
26		W	Low electric current	≤10A
27	Material	D	High resistance structural material to avoid deformations	
28		W	Low weight of the infotainment systems fixation	
29	Signals	D	Digital output and PC connection of the measurement sensors	
30		D	Display force-stroke diagram	
31		D	Save results	
32		W	Actuator and sensors with LabView drivers	
33		D	Sensors with high data refresh	
34	Safety	D	Safety controls to not damage the samples tested	
35	Ergonomics	D	Easy positioning of the infotainment system	
36	Assembly	W	Easy assembly and disassembly	
37	Operation	D	Destination: Development section or Lab section on a working table	
38		W	Easy operation control	
39	Maintenance	W	Low maintenance	
40	Costs	D	Total device cost	<10.000€
41	Schedule	W	Low delivery time of the components	
42		D	Hardware and button test software finished by	15 December
43		W	Pins connector tests software finished by	15 December

Table 4-1: Requirements list

4.2. Main functions of the design

A problem formulation should reflect the problem properly in order to achieve the final solution taking into account all the functions needed from the requirements list [12]. Conceptual design is the part of the design process where the principle solution is defined, by identifying the essential problems through abstraction, establishing function structures, searching for appropriate working principles and combining these into a working structure.

4.2.1. Overall function of the test device

The formulation begins with an abstract black box description of the processes to be performed to determine the main flow of the technical system.

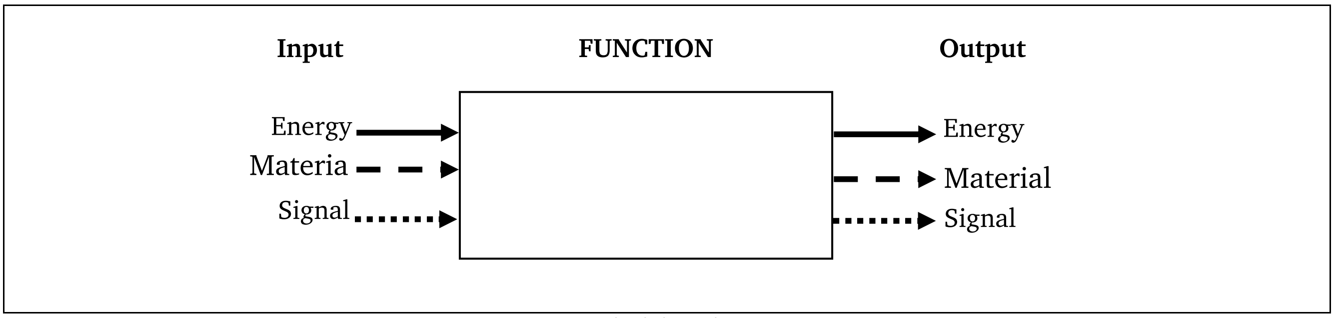


Figure 4-12: Black box description [12]

In **Figure 1-1**Figure 4-12, the general black box is described with the input flow and the output flow. Inside each one, the flows of energy, material and signal are defined. The main flow representation of the Infotainment System testing is shown at the Figure 4-13.

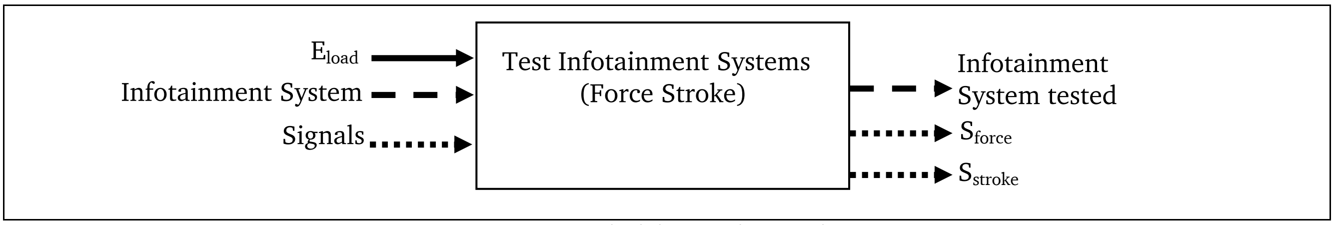


Figure 4-13: Black box of the test device

In this representation (Figure 4-13), the main functions and the input and output flows needed are shown. At the input side, the process needs the energy to achieve the aim of the function, the material (in this case the Infotainment System to be tested) and the signals to control and give the suitable parameters to perform the test. At the output side, the black box returns the Infotainment System tested and the signals of force and stroke measured by the test device.

4.2.2. Function structure of the test device

When the main flow is well defined, the next steps are going to be: getting inside the black box and describing the subfunctions of the system considering the auxiliary flows to achieve a further subdivision.

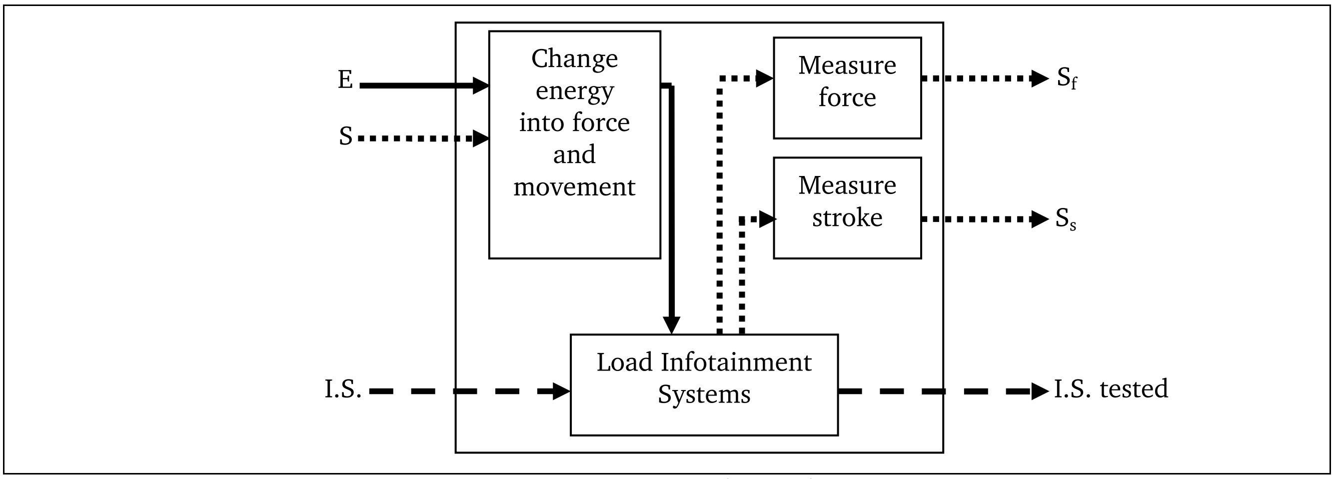


Figure 4-14: Function structure of the test device. First step.

In Figure 4-14, the main subfunctions that directly satisfy the required overall function are defined. In order to test automatically the Infotainment System a mechanism that change the energy into force and movement is needed. Moreover, at least two devices are needed to measure the required force and stroke.

In the next step, as is shown in the Figure 4-15, some subfunctions are added into the function structure diagram. These subfunctions are related to the treatment of the Infotainment System with the purpose to be tested correctly. In this case, a positioning system and a stable fixation are required. As it was defined at the Requirements list (Table 4-1), an automatic positioning system is wished and thus other energy and signal input are required.

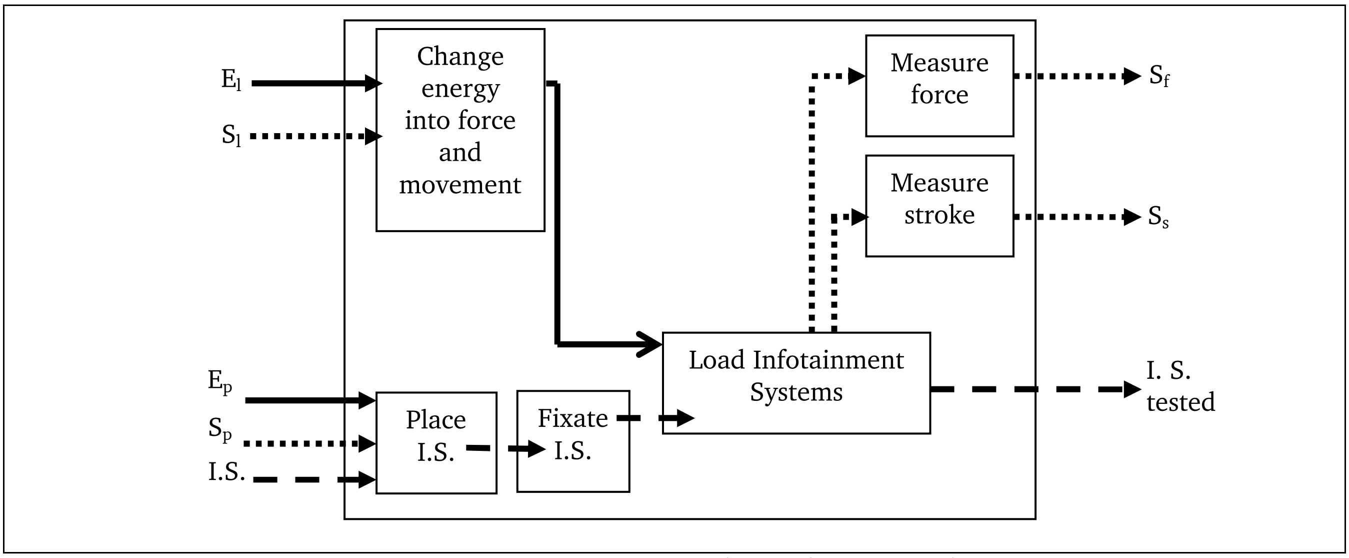


Figure 4-15: Function structure of the test device. Second step.

A safety system is needed for avoiding the damage of the force sensor used and the Infotainment System tested. The force sensor could be damaged by exceeding its force range. For these reasons, an auxiliary function is needed to compare the maximum force defined with the actual force value. Moreover, it is required to obtain the results at the output and to know if the characteristics tested are within tolerances. **Figure 1-1**Figure 4-16 shows the final function structure of the force-stroke test device.

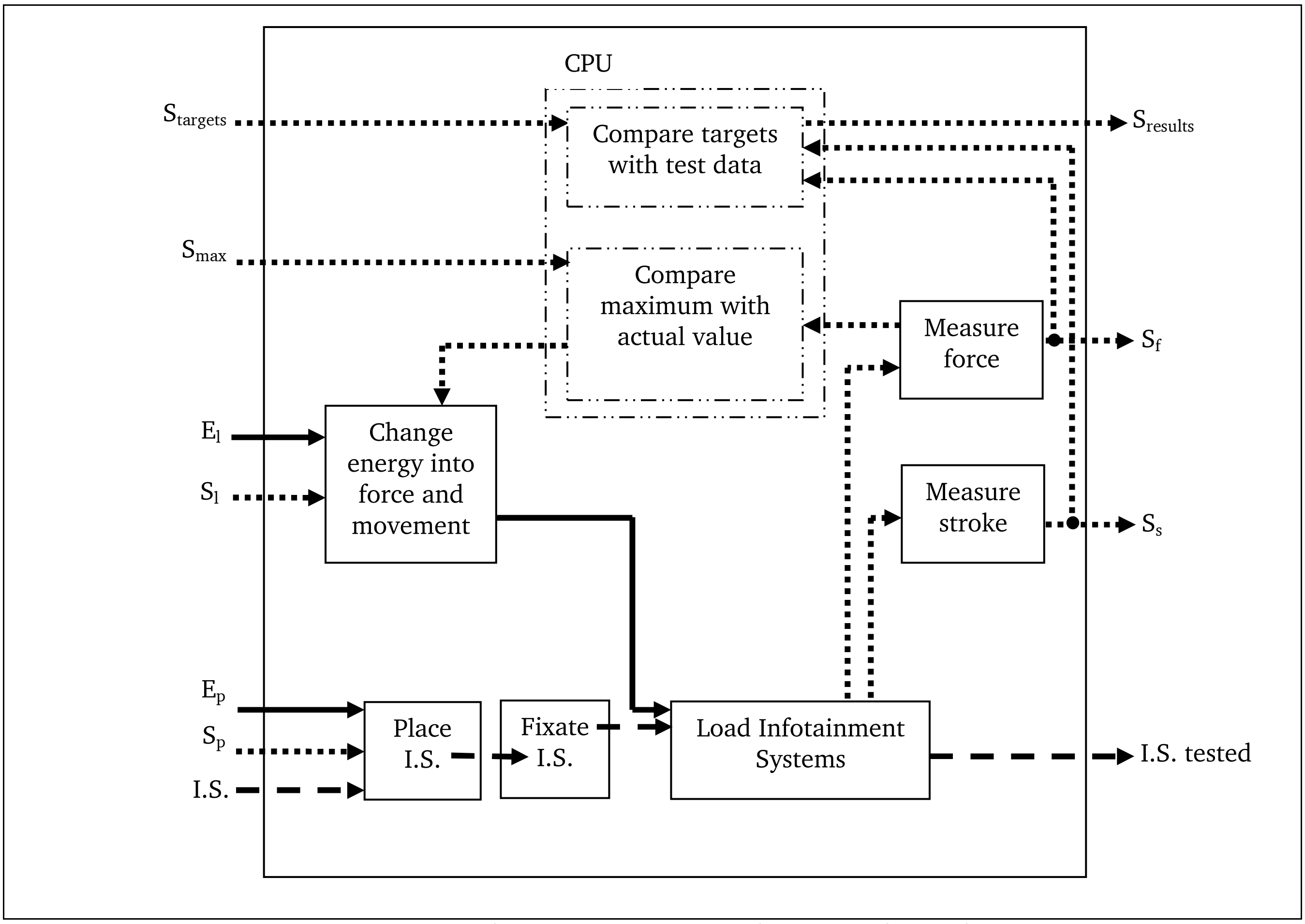


Figure 4-16: Complete function structure of the force-stroke test device

4.3. Solutions

The optimal solution is needed to be found for each subfunction of the function structure (Figure 4-16). These partial solutions are combined into a working structure. It is easier to achieve a global solution, dividing the problem into smaller parts and treating them separately. This has been done with the main function, subdividing it into small subfunctions. In this chapter, several variants for each subfunction are going to be discussed to combine them and reach to a global solution. The defined subfunctions are “Change energy into force and movement”, “Measure force”, “Measure displacement”, “Place the infotainment system”, “Fixate the infotainment system” and “Fixate all the components”. This chapter is considered a brainstorming of variants solutions.

4.3.1. Change energy into force and movement

The device able to change energy into force and movement is called actuator. The requirements that this component has to fulfil are described at the Table 4-2.

Requirements of the actuator			
Nr.	**D/W**	**Requirement**	**Quantification**
1	D	Automatic movement to perform the tests	
2	D	Linear movement	
3	D	Normal force applied	
4	D	Force range	0-500N
5	D	Speed range	0-10mm/s
6	D	Low speed working actuation	~0,1mm/s
7	D	Smooth application of the force	
8	D	Stroke high enough to sweep all infotainment systems heights	~150mm
9	W	Electrical primary energy	220V
10	W	Low electric current	≤10A
11	W	LabView drivers	
12	W	Low maintenance	
13	D	Low cost	
14	W	Low delivery time	

Table 4-2: Requirements of the actuator

Taking into account the primary energy that an actuator can use, at least three different kinds of actuators can be defined: electrical actuators; hydraulic actuators and pneumatic actuators.

Since using electricity as primary energy is a requirement wished, the other kinds will be discarded.

The most relevant electrical actuators for this application are showed at the Figure 4-17.

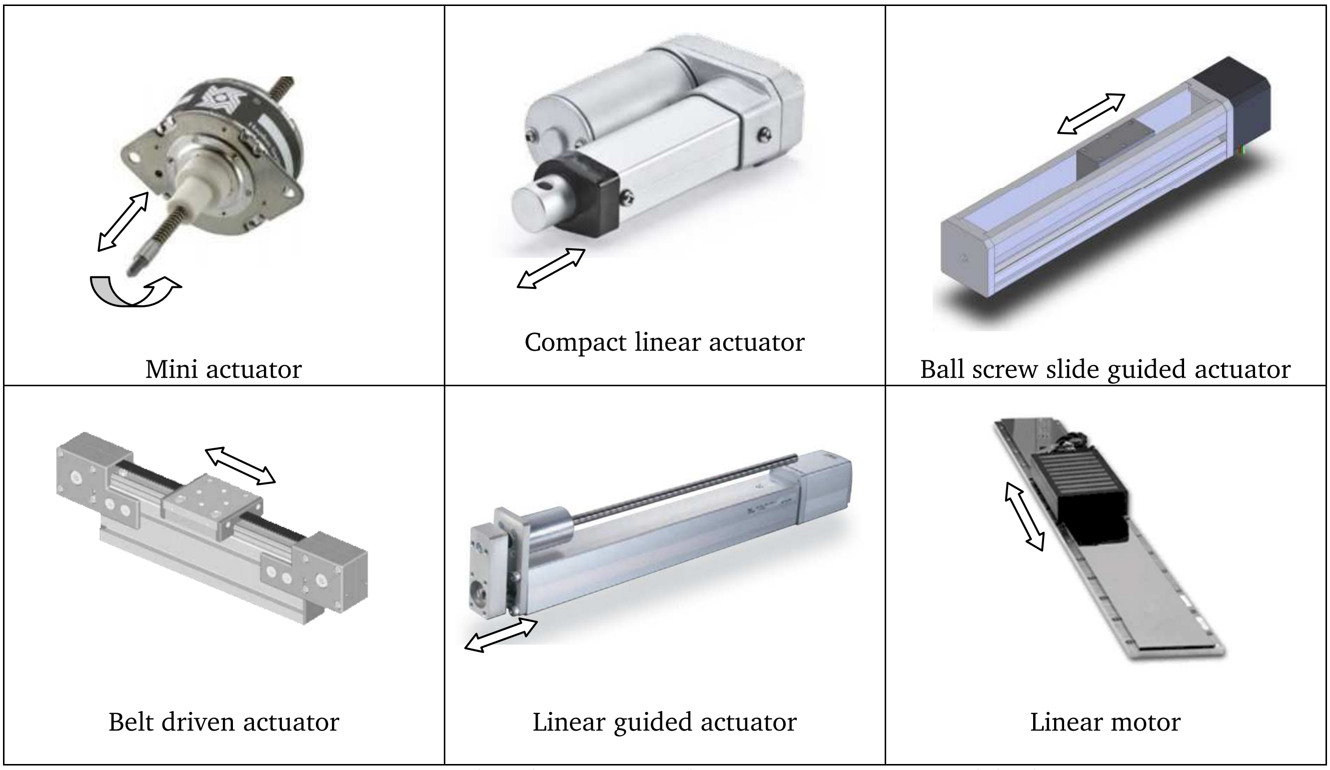


Figure 4-17: Variants for the subfunction of "Change energy into force and displacement"

4.3.2. Measure force

The device able to measure force is called force sensor. The requirements that this component has to fulfil are described at the Table 4-3.Table 4-2

Requirements of the force sensor			
Nr.	D/W	Requirement	Quantification
1	D	Force range	0-500N
2	D	Force resolution	≤0.01N
3	W	Force accuracy	≤±0.1N
4	W	Force repeatability	≤±0.1N
5	D	Digital output and PC connection	
6	W	LabView drivers	
7	D	High data refresh	
8	W	Low maintenance	
9	D	Low cost	
10	W	Low delivery time	

Table 4-3: Requirements of the force sensor

The most relevant force sensors for this application are showed at the Figure 4-18.

Force gauge

Load cell

Load bending beam

Z beam load cell

Figure 4-18: Variants for the subfunction of "Measure force"

4.3.3. Measure displacement

The device able to measure displacement is called displacement sensor. The requirements that this component has to fulfil are described at the Table 4-4.

Requirements of the displacement sensor			
Nr.	D/W	Requirement	Quantification
1	D	Stroke high enough to sweep all infotainment systems heights	
2	D	Displacement resolution	≤0.01mm
3	W	Displacement accuracy	≤±0.05mm
4	W	Displacement repeatability	≤±0.05mm
5	D	Digital output and PC connection	
6	W	LabView drivers	
7	D	High data refresh	
8	W	Low maintenance	
9	D	Low cost	
10	W	Low delivery time	

Table 4-4: Requirements of the displacement sensor

The most relevant displacement sensors for this application are showed at the Figure 4-19.

Magnetic linear encoder

Optical linear encoder

Inductive linear encoder

Digital scale

Linear scale

Digital indicator

Figure 4-19: Variants for the subfunction of "Measure displacement"

4.3.4. Place the infotainment system

The device able to place the infotainment system to the suitable position is called positioning system. The requirements that this component has to fulfil are described at the Table 4-2.

Requirements of the positioning system			
Nr.	**D/W**	**Requirement**	**Quantification**
1	W	Automatic positioning of the infotainment system	
2	D	Easy positioning of the infotainment system	
3	D	Precise positioning of the infotainment system	
4	W	Low maintenance	
5	D	Low cost	
6	W	Low delivery time	

Table 4-5: Requirements of the positioning system

The most relevant displacement sensors for this application are showed at the Figure 4-20.

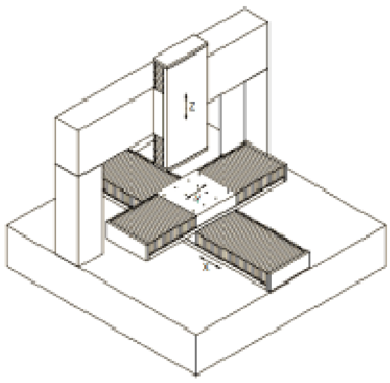
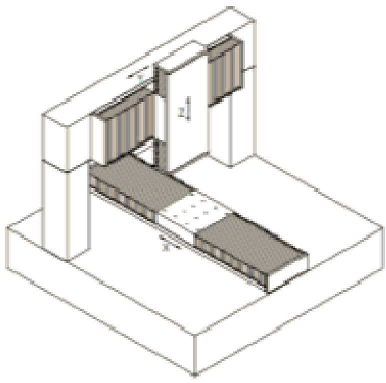
 Automatic movement X-Y of the infotainment system	 Automatic movement X of the infotainment system and automatic movement Y of the actuator	Manual movement of the infotainment system to place it to the suitable position.

Figure 4-20: Variants for the subfunction of "Place the infotainment system"

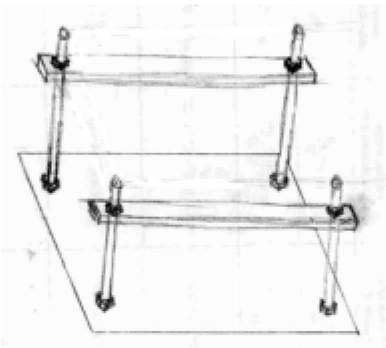
4.3.5. Fixate the infotainment system

The device able to fixate the infotainment system is called fixation system. The requirements that this component has to fulfil are described at the Table 4-4.

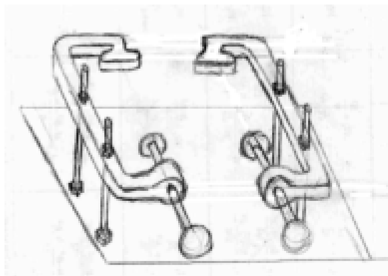
Requirements of the fixation system			
Nr.	**D/W**	**Requirement**	**Quantification**
1	D	Stable and rigid	
2	D	Polyvalent fixation for all infotainment system models	
3	W	Low weight	
4	D	Easy positioning of the infotainment system	
5	W	Easy assembly and disassembly	
6	W	Low maintenance	
7	D	Low cost	
8	W	Low delivery time	

Table 4-6: Requirements of the fixation system

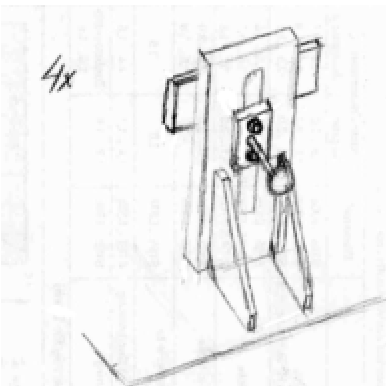
The infotainment system could be fixated in two orientations, vertical and horizontal. Furthermore, the fixation system must allow testing the infotainment system front side and rear side. Taking into account these considerations, the most relevant fixation systems for this application are showed at the Figure 4-21.



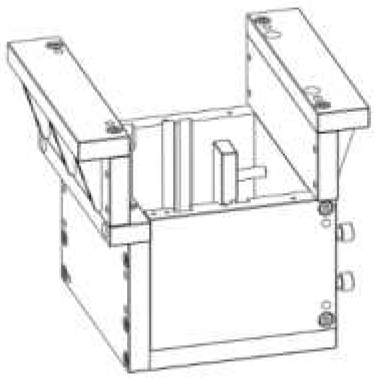
With the I.S. in horizontal orientation.



With the I.S. in vertical orientation.



With the I.S. in vertical orientation.



With the I.S. in vertical orientation.

Figure 4-21: Variants for the subfunction of “Fixate the infotainment system”

4.3.6. Fixate all the components

The device able to fixate all the components is called structure. The requirements that this component has to fulfil are described at the Table 4-4.

Requirements of the structure			
Nr.	**D/W**	**Requirement**	**Quantification**
1	D	Working place big enough to move freely all infotainment systems models and test all of their buttons	
2	W	Test device volume	$<1m^3$
3	D	Precise positioning of the infotainment system	
4	D	Easy positioning of the infotainment system	
5	D	Stable, stiff and robust	
6	D	High resistance structural material to avoid deformations	
7	W	Easy assembly and disassembly	
8	D	Destination: Development section or Lab section on a working table	
9	W	Low maintenance	
10	D	Low cost	
11	W	Low delivery time	

Table 4-7: Requirements of the structure

The most relevant structure configurations for this application are showed at the Figure 4-22.

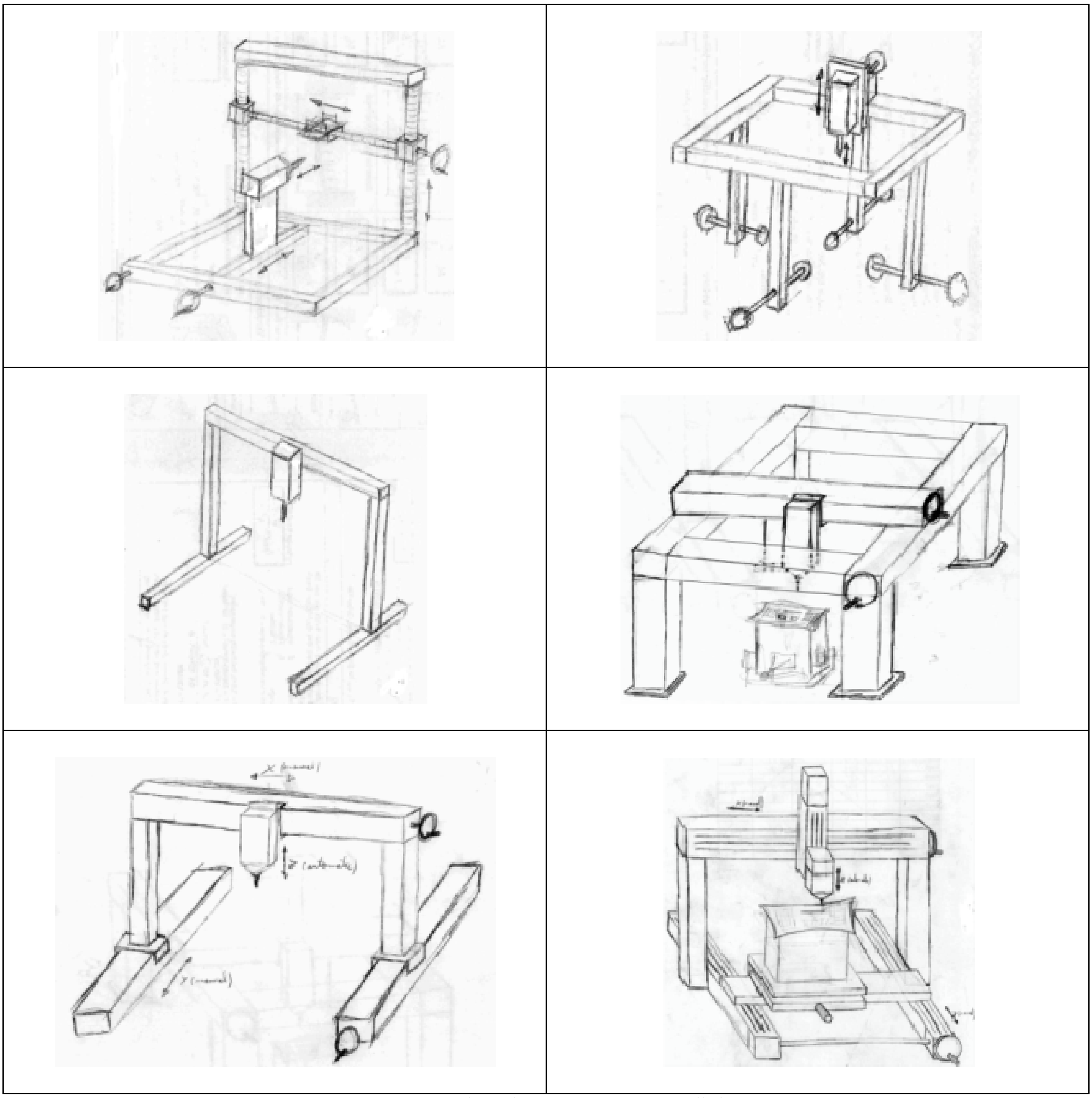


Figure 4-22: Variants for the subfunction of "Fixate all the components"

4.3.7. Solutions overview

Table 4-8 shows all the variants of the subfunctions together to give to each variant a coordinate name used in next chapters.

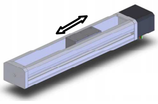
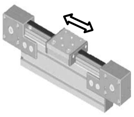
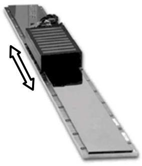
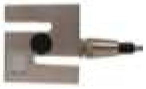
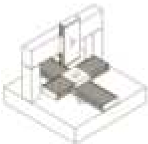
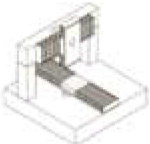
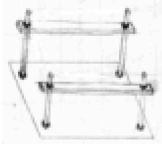
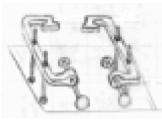
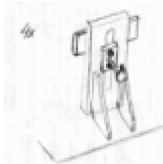
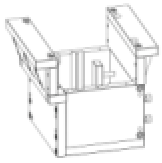
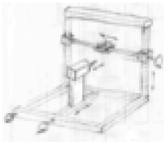
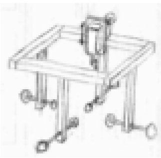
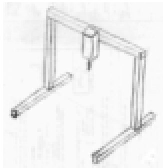
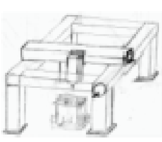
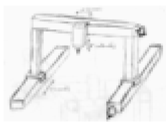
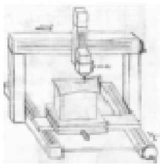
Solutions / Subfunctions	1	2	3	4	5	6
A Change energy into force and movement						
B Measure force						
C Measure displacement						
D Place the infotainment system			Manual movement of the infotainment system to place it to the suitable position			
E Fixate the infotainment system						
F Fixate all the components						

Table 4-8: Scheme with possible solutions for all the subfunctions identified

4.4. Working principles selection

4.4.1. Selection procedure of variants

The solution field shown in Table 4-8 is now evaluated for each subfunction's solution using a selection procedure. Table 4-9 shows the selection chart indicating the most promising subfunction solutions.

TU Darmstadt	SELECTION CHART for Force-Stroke Test Device	Part: 1 Page: 1

Solution variants (Sv) evaluated by SELECTION CRITERIA
(+) Yes
(-) No
(?) Lack of information
(!) Check requirements list

DECISION
Mark solution variants (Sv)
(+) Pursue solution
(-) Eliminate solution
(?) Collect information (re-evaluate solution)
(!) Check requirements list for changes

A: Compatibility assured
B: Fulfils demands of requirements list
C: Realisable in principle
D: Within permissible costs
E: Incorporates direct safety measures
F: Preferred by designer's company
G:

Enter solution variant (Sv):

Sv		A	B	C	D	E	F	G	Remarks (Indications, Reasons)	DECISION
A1	1	+	-						Low forces. Small displacements. Rotatory movement.	-
A2	2	+	-						Dificulties for use it at low speed range. Not safety.	-
A3	3	+	+	+	-	+				+
A4	4	+	+	-					Not stiff enough. Slide. Not sharp stop possible.	-
A5	5	+	+	+	+	+				+
A6	6	-	+	-	-				It is not possible to use it in vertical orientation. Very high cost.	-
B1	7	+	+	+	+	-				+
B2	8	+	+	+	+	-				+
B3	9	+	+	-					Deformation of the sensor. Displacement measured not exact.	-
B4	10	+	+	-					Deformation of the sensor. Displacement measured not exact.	-
C1	11	+	+	-	-				Low tolerances of instalation. Measurement is interfered by vibrations.	-
C2	12	+	+	-	-				Low tolerances of instalation. Measurement is interfered by vibrations.	-
C3	13	+	+	-	-				Low tolerances of instalation.	-
C4	14	+	+	+	+	-				+
C5	15	+	+	+	-	-				+
C6	16	+	+	+	+	-				+
D1	17	+	+	+	-	+			Too expensive.	-
D2	18	+	+	+	-	+			Too expensive.	-
D3	19	+	+	+	+	+				+
E1	20	+	+	+	+				Only for horizontal orientation of the infotainment system.	+
E2	21	+	-						It is not a stable system.	-
E3	22	+	+	+	+				It is not easy to fixate correctly the infotainment system.	-
E4	23	+	+	+	-				It is heavy and expensive.	+
F1	24	+	-	-	-				Difficult positioning of the infotainment system. Not stable. Expensive.	-
F2	25	+	-	-					It is not possible to fixate the infotainment system accurately.	-
F3	26	+	+	+	+				Structural simplicity. Low cost. Not automatic I.S. positioning.	+
F4	27	+	+	+	-				Not stiff enough to get accurate measurements. Expensive.	-
F5	28	+	+	+	-				Not stiff enough to get accurate measurements. Expensive.	-
F6	29	+	+	+	-				Not stiff enough to get accurate measurements. Expensive.	-

Date: Jan 11	Initials: JR	

In the following paragraphs, the reasons of rejecting a given variant will be discussed.

Taking into account the demanded requirements of “Change energy into force and displacement” subfunction, the Mini actuator (A1) and the Compact linear actuator (A2) has been rejected. The first one (A1) is not able to apply a force of 500N and the maximum displacement is not enough for being able to test all models of infotainment system regardless of their height. Moreover, this actuator transmits rotatory movement. It would be a possible solution for the buttons test but not for the pins connector test. About the compact linear actuator (A2), its speed of actuation is not possible to be controlled, and the speed varies only with the working load. One solution could be using a pulse width modulation (PWM) control technology to reduce its nominal speed, but reducing it to less than 0,1mm/s could damage the motor and it is not safe. The Ball screw slide guided actuator (A3) is a good variant solution for this subfunction. It can fulfil all the requirements and has high thrust and stiffness. Furthermore, this kind of actuator has a high accuracy, resolution and repeatability. Talking about the Belt driven actuator (A4), although it fulfils all the requirements, the backlash of this kind of actuator is too high, it is not stiff and accurate enough and could not perform a sharp stop. Thus, it is not suitable for this application. The Linear guided actuator (A5), using a step motor, fulfils perfectly all the requirements. Its performance is satisfactory and the guide implemented to its structure avoids the necessity of using another guide to lead the sensors. And finally, talking about the linear motor (A6), it is not suitable for actuating in vertical orientation, a sharp stop is not possible and its cost is too high.

The Load bending beam (B3) and the Z beam load cell (B4) have been rejected because of their principle of operation. These kinds of sensors measure the force applied by means of the deflection of the beam. Although the maximum deflection is low (for the load bending beam is about 0,15mm), they would cause errors to the displacement measurement that must be avoided. The force gauge (B1) and the load cell (B2) fulfil all the requirements.

The three first displacement sensors (C1-C3) fulfil all the requirements and have very high resolution, accuracy and repeatability but they have been rejected because of their very narrow tolerances of installation and performance in order that they could work correctly. For this application, these tolerances of alignment, parallelism and gap between the reading head and the scale could not be warranted. Furthermore, the possible vibrations of the actuator during its performance could cause measurement errors of these kinds of sensors. On the contrary, the last three sensors showed (C4-C6) need an easy installation and the installation and performance tolerances are not so narrow. Moreover, they fulfil all the requirements demanded.

The automatic configurations (D1 and D2) to place the infotainment systems in the suitable position have been rejected because of their high cost. Thus, all possible measures to ensure the easy positioning of the infotainment systems manually will be taken.

The fixation system selected is the E4. Although it is the heaviest and the most expensive one, it is the most stable, robust, rigid and safe fixation to test any kind of infotainment systems in vertical orientation regardless the side of the infotainment system to be tested. The E1 fixation system has been rejected because it is only for horizontal orientation of the infotainment systems, and the structure selected needs the infotainment system in vertical orientation. And E2 and E3 fixation systems are not stable and rigid enough and it is not easy to fixate the infotainment systems correctly with these fixations.

Finally, taking into account all the requirements, the most suitable structure for the application of this project is the F3, which is the simplest, the most stable and robust and the cheapest one. The F1 structure with the infotainment system in horizontal orientation has a configuration too complex that does not ensure a good stability for measuring force and displacement avoiding possible errors caused for gaps of the positioning systems of the infotainment system and of the actuator. F2 is not a realizable principle and the positioning of the infotainment system at the suitable place is not an easy task using this structure. The F4, F5 and F6 structures fulfil all the requirements although using two more actuators (automatic or manual) increase the cost of the structure and could introduce random errors to the measurements of force and displacement due to the gaps and slides into the guides.

4.4.2. Concept evaluation and determination

4.4.2.1. Change energy into force and movement

Nr.	Evaluation Criteria	Wt.	Parameters	Unit	Variant A3 (Ball screw slide guided actuator) Aerotech Magn. m_{i1}	Value V_{i1}	Weighted Value WV_{i1}	Owis Magn. Mi2	Value V_{i2}	Weighted Value WV_{i2}	SKF Magn. Mi3	Value V_{i3}	Weighted Value WV_{i3}	Variant A5 (Linear guided actuator) IAI Magn. Mi4	Value V_{i4}	Weighted Value WV_{i4}
1	Low price	0,4	Price	€	11.325,00	0	0	11.609,80	0	0	6.107,00	3	1,2	1.380,00	9	3,6
2	Simple assembly	0,1	Simplicity of assembly	-	high	7	0,7	high	7	0,7	high	7	0,7	high	7	0,7
3	High compatibility with the components rest	0,1	Compatibility with the components rest	-	low	3	0,3	low	3	0,3	low	3	0,3	very high	9	0,9
4	High accuracy	0,05	Accuracy	µm	3	7	0,35	3	7	0,35	40	5	0,25	50	5	0,25
5	High resolution	0,1	Resolution	µm	0,0005	7	0,7	0,001	6	0,6	0,001	6	0,6	0,01	4	0,4
6	High repeatability	0,05	Repeatability	µm	0,001	7	0,35	0,003	7	0,35	0,01	6	0,3	0,02	5	0,25
7	Suitable comunication interface	0,1	Comunication interface	-	USB+ LabView dirvers	8	0,8	USB+ LabView dirvers	8	0,8	RS232	5	0,5	USB+ Modbus protocol	5	0,5
8	Low delivery time	0,1	Delivery time	weeks	9	1	0,1	8	1	0,1	6	4	0,4	4	7	0,7
		ΣWt= 1.0														
	$OWV_u = \Sigma(WV_{iu}\ di)$						3,3			3,2			4,25			7,3
	$WR_u = OWV_u/\Sigma(OWV_u\ du)$						0,18			0,18			0,24			0,40

Table 4-10: Evaluation chart for "Change energy into force and movement" subfunction

There are two variants possible to carry out the “Change energy into force and displacement” subfunction. Three Ball screw slide guided actuators that fulfil all the requirements have been found but there is only one suitable for the linear guided actuator variant. In order to select the appropriate actuator, the specific actuator’s characteristics from each company have to be taken into account because the main characteristics vary from one company to another. Moreover, it is needed to provide different weight to each evaluation criteria because some requirements are more important than others.

The price is a very important selection criterion. The budget of this project is small and although the actuator is an important component for the device, it should not consume the entire budget. For this reason, the “Low price” evaluation criterion has a high weight at the Evaluation chart (Table 4-10).

For this application it is not necessary that the actuator has high accuracy and repeatability because external displacement and force sensors will be used and these will control the performance of the actuator to achieve the tests correctly. On the other hand, a high resolution is needed because this value will determine the minimum step of the actuator movement, and as an actuation speed of about 0,1mm/s is required, 0,01mm resolution will be enough.

A “Compatibility with the components rests” criterion is also an important evaluation criteria and it is related to how the components rest interact with the actuator. The most important interaction are between the actuator and the displacement sensor, to measure with high accuracy and resolution the actuator’s stroke, and between the actuator and the force sensor, to measure with high accuracy and resolution the force applied. For both actuator variants the simplicity of the assembly between the displacement sensor mobile part and the actuator mobile part are the same. On the contrary, the ways to assemble the force sensor to the actuator mobile part from the two variants are very different. On one hand, with the Ball screw slide guided actuator, the length of the fixation between the force sensor and the actuator’s slide is too long. It must be equal to the stroke needed to sweep all the infotainment systems height plus the length of the slide and minus the length of the force sensor, in order that, when the actuator is at the home position, the force sensor end would exceed the actuator (See Figure 4-23). So, the whole stroke of the actuator could be useful to perform the tests. This is not a suitable configuration because high deflection torques will affect to the fixation at 400N test and it will affect the accuracy of the measurement characteristics.

Figure 4-23: Fixation between the force sensor and the actuator's slide

On the other hand, with the Linear guided actuator, this problem disappears and the performance for the test device is optimized.

Another important criterion is the delivery time. It must be low in order that there will be enough time to assemble all components of the device and test the device performance before the deadline. Because of this criterion, one suitable actuator from the company Thomson Linear Motion was directly rejected after having a meeting with a busninessman of the company and realise that the delivery time of the actuator had been increased to 14 weeks because of factory problems.

Taking into account all these criteria and evaluating the four actuator models, the Linear guided actuator from IAI is the one chosen because of its properties.

4.4.2.2. Measure force

There are two variants possible to carry out the “Measure force” subfunction, the Force gauge sensor and the Load cell sensor.

For evaluating the force sensor variants, the main criteria are the price, the accuracy and the compatibility with the components rest.

Evaluation Criteria			Parameters		Variant B1 (Force gauge)			Variant B2 (Load cell)		
Nr.		Wt.		Unit	Magn. M_{i1}	Value V_{i1}	Weighted Value WV_{i1}	Magn. M_{i2}	Value V_{i2}	Weighted Value WV_{i2}
1	Low price	0,2	Price	€	high	5	1	averaged	7	1,4
2	Simple assembly	0,1	Simplicity of assembly	-	high	7	0,7	high	7	0,7
3	High compatibility with the components rest	0,2	Compatibility with the components rest	-	averaged	5	1	high	8	1,6
4	High accuracy	0,2	Accuracy	N	high	7	1,4	high	7	1,4
5	High resolution	0,1	Resolution	N	high	7	0,7	high	7	0,7
6	Suitable comunication interface	0,1	Comunication interface	-	USB	8	0,8	USB	8	0,8
7	Low delivery time	0,1	Delivery time	weeks	low	9	0,9	low	9	0,9
		$\Sigma Wt = 1.0$								
	$OWV_u = \Sigma(WV_{iu}\ di)$						6,5			7,5
	$WR_u = OWV_u / \Sigma(OWV_u\ du)$						0,46			0,54

Table 4-11: Evaluation chart for “Measure force” subfunction

As shown in the Table 4-11, the two variant of force sensors have similar accuracy and resolution. However, the Load cell is cheaper and has better compatibility with the component rests. The Load cell is smaller, for its fixation to the actuator it is only needed a metal plate screwed to the actuator head and it does not need an external energy supplier or a battery charger because it only uses the energy from the USB connector. Thus, it allows that the structure and the force sensor fixation would be more compact, more robust and simpler.

4.4.2.3. Measure displacement

There are three variants possible to carry out the "Measure displacement" subfunction, the Digital scale, the Linear scale and the Digital indicator.

For evaluating the displacement sensor variants, the main criteria are the price, the accuracy, the repeatability and the compatibility with the component rests. The evaluation criteria of measurements per second and communication interface have very low weight for this evaluation but it does not mean that these criteria are less important. The lack of measurements per seconds could be compensated by interpolating between the data obtained.

As shown in the Table 4-12, the Digital indicator is the best variant for this application. Its installation is very simple, its price is quite low and it has a high compatibility with the component rests. In order to measure the displacement of the actuator, the end of the digital indicator only has to contact the force sensor fixation screwed to the actuator's head.

Nr.	Evaluation Criteria	Wt.	Parameters	Unit	Variant C4 (Digital scale) Magn. M_{i1}	Value V_{i1}	Weighted Value WV_{i1}	Variant C5 (Linear scale) Magn. M_{i2}	Value V_{i2}	Weighted Value WV_{i2}	Variant C6 (Digital indicator) Magn. M_{i3}	Value V_{i3}	Weighted Value WV_{i3}
1	Low price	0,15	Price	€	low	8	1,2	high	4	0,6	averaged	6	0,9
2	Simple assembly	0,1	Simplicity of assembly	-	high	7	0,7	high	7	0,7	high	7	0,7
3	High compatibility with the components rest	0,15	Compatibility with the components rest	-	averaged	6	0,9	high	7	1,05	high	9	1,35
4	High accuracy	0,15	Accuracy	µm	low	4	0,6	high	8	1,2	high	7	1,05
5	High resolution	0,1	Resolution	µm	averaged	6	0,6	high	8	0,8	high	8	0,8
	High repeatability	0,15	Repeatability	µm	low	4	0,6	high	7	1,05	high	7	1,05
	High data refresh	0,05	Measurements/second	s^{-1}	averaged	6	0,3	high	8	0,4	averaged	7	0,35
6	Suitable comunication interface	0,05	Comunication interface	-	RS233	5	0,25	RS421	5	0,25	USB	8	0,4
7	Low delivery time	0,1	Delivery time	weeks	low	8	0,8	averaged	7	0,7	averaged	7	0,7
		$\Sigma Wt=$ 1.0											
	$OWV_u = \Sigma(WV_{iu}\ di)$						5,95			6,75			7,3
	$WR_u = OWV_u/\Sigma(OWV_u\ du)$						0,47			0,53			0,52

Table 4-12: Evaluation chart for "Measure displacement" subfunction

4.5. Final design

The Figure 4-24 and Figure 4-25 show the final configuration of the Force-stroke test device already assembled. In both figures the actuator is at the home position ready to perform the respective test. In the Figure 4-24 the Infotainment system is placed face up inside its fixation ready to perform the Button test. At Figure 4-25 the Infotainment System is inside its fixation with the feet assembled, placed face down and fixed to the test device table, by means of for clamps, ready to perform a pins connector test.

Figure 4-24: Force-stroke test device at buttons test

Figure 4-25: Force-stroke test device at pins connector test

In order to achieve the final design, the following steps have been taken:

1. Predesign of the structure
2. Select the suitable actuator
3. Select the suitable force sensor
4. Select the suitable displacement sensor
5. Design the fixation of the components (actuator, sensors and infotainment system)
6. Modify the structure design to fit all the parts

The general characteristics of the test device are showed at the Table 4-13.

Category	Characteristics

Geometry	- Overall dimensions:
	  - Length: 600mm
	  - Width: 700mm
	  - Height: 860mm
	- Working place dimensions:
	  - Length: 445mm
	  - Width: 600mm
	  - Height: 375mm

Kinematics	- Actuation:
	  - Max. stroke: 100mm
	  - Speed range: 0,01-150mm/s
	- Displacement measurements:
	  - Resolution: 1µm
	  - Accuracy: ±8 µm
	  - Repeatability: ±2 µm

Statics	- 4 clamps for Infotainment System fixation

Forces	- Two force sensors:
	  - Force sensor A:
	    ▪ Force range: 0-20 N
	    ▪ Resolution: 1 µN
	    ▪ Accuracy: ±0,1 N
	  - Force sensor B:
	    ▪ Force range: 0-500 N
	    ▪ Resolution: 10 µN
	    ▪ Accuracy: ±1 N

Energy	- Power supply:
	  - 24V DC
	  - 2A

Material	- Structure profiles: EN-AW-6060 T6 - Fixation parts: EN-AW-2007 - Force sensor ends: S235JR
Signals	- 4 USB connectors

Operation	- Graphic application interface (developed using LabView)
	- Results given in images and spreadsheet
	- Tests to perform:
	  - Button test
	  - Plug test
	  - Cable test
	  - Unplug test
	  - Pins test
	  - Possibility to configure new tests
	- Degree of protection: IP 51 (according to IEC 529

Cost	- 8840€

Table 4-13: Force-stroke test device general characteristics

In the following figures (from Figure 4-26 to Figure 4-30), the different groups of the test device are highlighted.

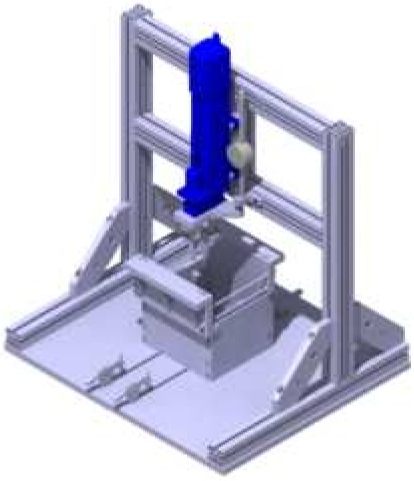


Figure 4-26: Actuator

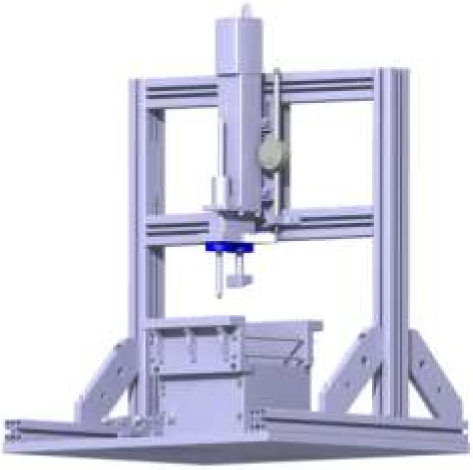


Figure 4-27: Force sensors

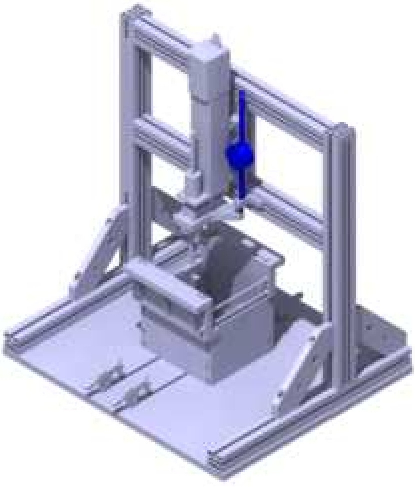


Figure 4-28: displacement sensor

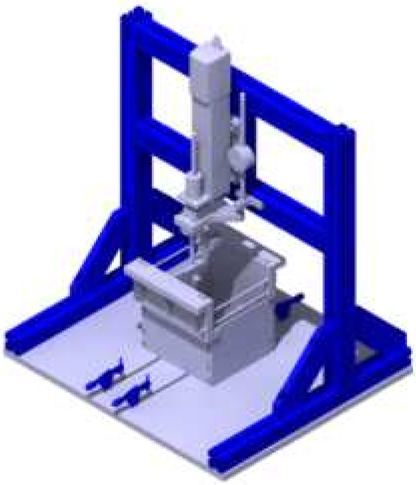


Figure 4-29: Structural components

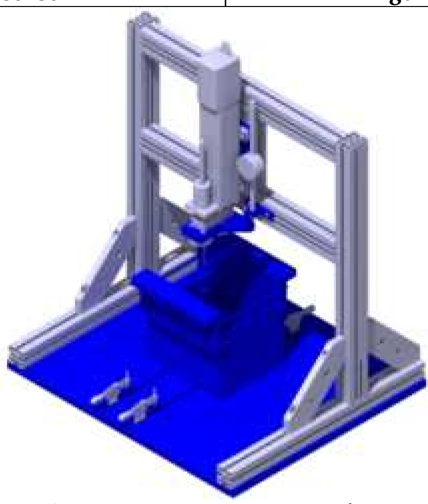


Figure 4-30: Non-commercial parts

4.5.1. Selected components

In order to find the suitable components, many companies have been searched and many calls meetings with suppliers have been done.

In the following subsections, all commercial component used for the final design will be defined. Appendix B shows the tables with the information of the main suppliers of each component that have been used in order to select the suitable one.

4.5.1.1. Actuator

Actuator

Controller

Company	IAI Robocylinder
Components	a) Actuator: - RCP2-RGS6C-I-56P-4-100-P1-S-B b) Controller: - PCON-CG-56PI-PN-2-0 c) Cable: - RCM-101-USB-EU
Price	a) 960,00€ b) 170,00€ c) 250,00€ Total: 1380,00€
Accuracy	± 0,05mm
Resolution	0,01mm
Repeatability	± 0,02mm
Max. force	800N (push and pull)
Stroke	100mm
Motor type	Step motor (800P/Rev)
Lead	4mm
Power supply	24V DC
Communication interface	USB + Modbus Protocol
Delivery time	4 weeks

Table 4-14: Selected actuator characteristics

The optimal stroke of the actuator would be 150mm. But the stroke has been reduced 50mm in order to save 382€ of the Digital indicator. If these 50mm are required in the future for adjusting to new models with a height out of the range, the fixation of the actuator could be moved 25mm down or up from the actual position (See section 4.5.2).

4.5.1.2. Force sensor

Force sensor A

Force sensor B

Company	Burster
Components	a) Force sensor A: - 8523-20 b) Force sensor B: - 8523-500 c) 2x USB-Interface: - 9205-V001 d) 2x Adjustment of the USB-Sensor-Interface
Price	a) 355,00€ b) 350,00€ c) 690,00€ d) 80,00€ Total: 1475,00€
Force range	a) 0-20N (tension and compression) b) 0-500N (tension and compression)
Accuracy	a) ± 0,5% v.E (± 0,1N) b) ± 0,2% v.E (± 1N)
Resolution	a) 0,001N b) 0,01N
Measurement rate	2500 readings/s
Power supply	USB
Communication interface	USB
Delivery time	1 week

Table 4-15: Selected force sensors characteristics

Two force sensors have been selected because the ranges of actuation for the tests are very different. For the button test, a high accuracy is needed and its force range is 10N. For the pins connector tests, a high accuracy is not needed and its force range is 450N. It is not possible to use the same force sensor for the both groups of tests because the accuracy is a percentage of the sensor range, and the 500N force sensor does not provide the accuracy required for the button test.

Designing the force sensors fixation, that will be screwed to the actuator's head, the 500N force sensor axis has been placed aligned with the actuator axis, in order to avoid excessive torques.

4.5.1.3. Displacement sensor

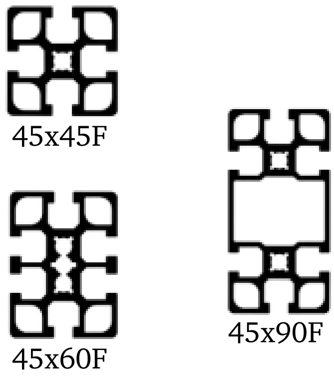
Company	Studenroth (Sylvac)
Components	a) Digital indicator: - 2101-1045 b) USB cable: - 5001-3031
Price	a) 599,00€ b) 81,50€ Total: 680,50€
Measuring range	100mm
Accuracy	± 8µm
Repeatability	± 2 µm
Resolution	0,001mm
Measurement rate	5 readings/s
Power supply	Battery
Communication interface	USB
Delivery time	3-4 weeks

Table 4-16: Selected displacement sensor characteristics

As mentioned in the selection of the actuator, the optimal stroke for the application would be 150mm, but the Studenroth digital indicator of 100mm had a reduction of 110€ from its normal price. The reduction of 50mm stroke has saved 382€ from the total cost.

This digital indicator has a very low measurement rate, only 5 readings/s, and the 2101-1050 force sensor model from the same company has a measurement rate of 8 readings/s. However, the accuracy, the repeatability and the resolution of the second one are ±20 µm, ±20 µm and 0, 01mm, respectively. Because of that, it is more important to have high performance characteristics and lower measurement rate. In conclusion, the 2101-1045 digital indicator model has been chosen and an interpolation function will be programmed to obtain more data between measurement collection.

4.5.1.4. Structural profiles



Company	Minitec
Components	a) 45x45F b) 45x60 c) 45x90F
Price	a) 12,80€/m b) 25,30€/m c) 25,70€/m
Material	EN-AW-6060 T6
Young's modulus (E)	70.000 N/mm^2
Shear modulus (G)	27.000 N/mm^2
Min. $R_{p0,2}$	200N/mm^2
Delivery time	1 week

Table 4-17: Selected profiles characteristics

The 45x60 profile has been selected for the main pillars and for the lintels, the 45x90F profile has been selected for the central pillar, where the actuator will be fixed, and the 45x45F profile has been selected for the structure's feet. The pre-selection of the profiles are showed at the Appendix B and the verification will be shown in the section 4.5.2. (Structure design).

4.5.1.5. Clamps

Company	Minitec
Components	a) 4x Horizontal clamp - GN 820.1-75-N b) 4x Clamping bolt - GN 807-M5-38-A
Price	a) 41,16€ b) 0,96€ Total: 42,12€
Holding force (F_H)	900N
Delivery time	1 week

Table 4-18: Selected clamps characteristics

Four horizontal clamps have been selected to fixate the Infotainment System fixation to the table's device when the pins connector tests are performed. These clamps are needed in order that the infotainment system does not move when the actuator pull the pins connector and is the simplest and easiest way to do that. This clamp configuration has been selected because is the one that fits better with the design. The clamps are oversized because the maximum force that each one has to hold is 112,5N, but it is the smallest model for this clamp configuration. Furthermore, it is needed four clamps for a stable fixation of the infotainment system.

4.5.1.6. Price list

COMPONENT	COMPANY	MODEL	UNITS	PRICE UNIT [€/u]	PRICE [€]
Actuator	IAI	RCP2-RGS6C-I-56P-4-100-P1-S-B	1	960,00	960,00
		PCON-CG-56PI-PN-2-0 (controller)	1	170,00	170,00
		RCM-101-USB-EU (cable+softw)	1	250,00	250,00
					1380
Force Sensor	Burster	8511-5010 (load bending beam)	1	355,00	355,00
		8523-500 (load cell)	1	350,00	350,00
		9205-V001 (USB-Interface)	2	345,00	690,00
		9205-ABG (Adjustment of the USB-Sensor-Interface)	2	40,00	80,00
					1475
Displacement sensor	Studenroth (Sylvac)	2101-1045 (digital indicator)	1	599,00	599,00
		5001-3031 (datenkabel USB)	1	81,50	81,50
					680,5
Structure	Minitec	Profil 45x60x600 20.1023/0	2	17,18	34,36
		Profil 45x60x685 20.1023/0	2	19,33	38,66
		Profil 45x90Fx210 20.1032/0	1	7,40	7,40
		Profil 45x45Fx600 20.1033/0	2	9,68	19,36
		Power-lock Fastener 21.1018/0	16	2,60	41,60
		Corner 180 21.1784/0	4	21,50	86,00
		Screw M6x16 21.1238/0	2	0,10	0,20
		Screw M6x25 21.1242/0	6	0,10	0,60
		Screw M8x20 21.1202/0	4	0,12	0,48
		Screw M8x25 21.1204/0	12	0,18	2,16
		Nut M6 21.1330/2	2	0,40	0,80
		Nut M8 21.1351/2	12	0,40	4,80
		Nut M8 21.1351/0	4	0,23	0,92
		Washer M8 21.1360/0	4	0,13	0,52
		Cable clip 22.1204/0	10	0,70	7,00
		End cap 45x60 22.1058/0	2	1,00	2,00
		End cap 45x45 22.1067/0	4	0,55	2,20
					249,06
	Ganter Griff	"Horizontal-Spanner" GN 820.1-75-N	4	10,29	41,16
		"Andrückschrauben" GN 807-M5-38-A	4	0,24	0,96
					42,12
Non-comercial parts	Schoder	Actuator fixation	1		
		Actuator foot	2		
		Clamp fixation	4		
		Digital indicator fixation L	1		
		Digital indicator fixation R	1		
		Fastening extra set	1		
		Foot 1	1		
		Foot 2	1		
		Foot 3	1		
		Foot 4	1		
		Foot 5	1		
		Foot 6	1		
		Feet assembly	1		
		Load cell end button test	1		
		MIB spacer	2		
		Radio fixation 1	1		
		Radio fixation 2	1		
		Radio fixation 3	1		
		Radio fixation 4	1		
		Radio fixation 5	1		
		Radio fixation 6	1		
		Radio fixation assembly	1		
		Screw guide m10x80	4		
		Sensor fixation	1		
		Spacer L	1		
		Spacer R	1		
		Table	1		
		Threaded rod	4		
		Load cell end cable fixation	1		
		Load cell end plug test MIB	1		
		Load cell end plug test	1		
		Load cell end connection	1		
		Fastening extra set 2	1		
					5012,00
			Commercial parts		3.826,68
			Non-commercial part		5.012,00
			Total price		8.838,68

Table 4-19: Price list

4.5.2. Structure design

A very important component of a test device is its structure. All components of the device are supported by it and their fixation must be assured. The structure must be stable, stiff and robust enough in order to obtain accurate measurements.

The simplest and cheaper solution for the structure is the use of extruded aluminium profiles. The qualities inherent in extruded aluminium profiles also offer freedom, versatility, and reliability to the design.

Extruded aluminium profiles are available in a wide variety of shapes. The most used extruded aluminium profile type in the engineering industry is the one with T shape longitudinal cavities. These cavities provide to the profile a great compatibility with other elements simplifying their connection and fixation. These profiles are modular, they could be fastened and assembled easily and it is possible to reconfigure the assembly quickly. Even though this kind of profile has light weight, it has good strength and longer life than items made from steel or plastic. They are corrosion resistant and it is not necessary to paint or protect them against external agents. Moreover, the extruded aluminium profiles are cheap and have wide range of accessories and short lead time.

The pre-calculus for obtaining an approximate deflection at the worst load case and selecting the suitable section are described in Appendix B. The profiles selected (Figure 4-31) were defined in Table 4-17.

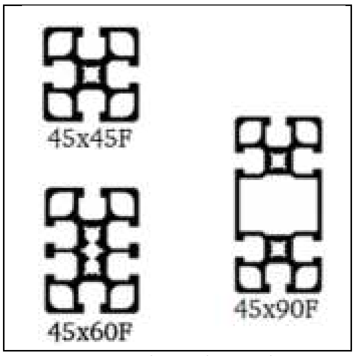
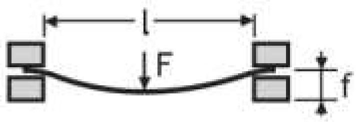


Figure 4-31: Selected profile sections

The final design of the structure is shown in the Figure 4-32. The structure consists of two pillars (45x60Fx685mm), two lintels (45x60Fx600mm), one intermediate pillar (45x90Fx210mm) and two feet (45x45Fx600mm). All profiles are orientated correctly to work with their maximum moment of inertia (I) in order to reduce their deflection (See Equation 1).



$$f = \frac{F \times l^3}{192 \times E \times I}$$

Equation 1: Deflection of a beam with two fixed supports and centred load [15]

The length of the pillars and lintels are determinate by the free space of the working place requested. The width of the intermediate pillar was defined higher than the other profiles' width to provide a higher surface fixation for the actuator. The length of this pillar is determinated by the separation of the actuator's foot plus 50mm. In the future, if there is an infotainment system model whose height is out of the normal height range (See Table 4-1: Requirements list), the actuator's fixation would be able to be moved 25mm up or down in order to fit into the new model requirements. Moreover, two feet are used in order to provide to the structure with higher stability and make easier the fixation of the structure to the device table.

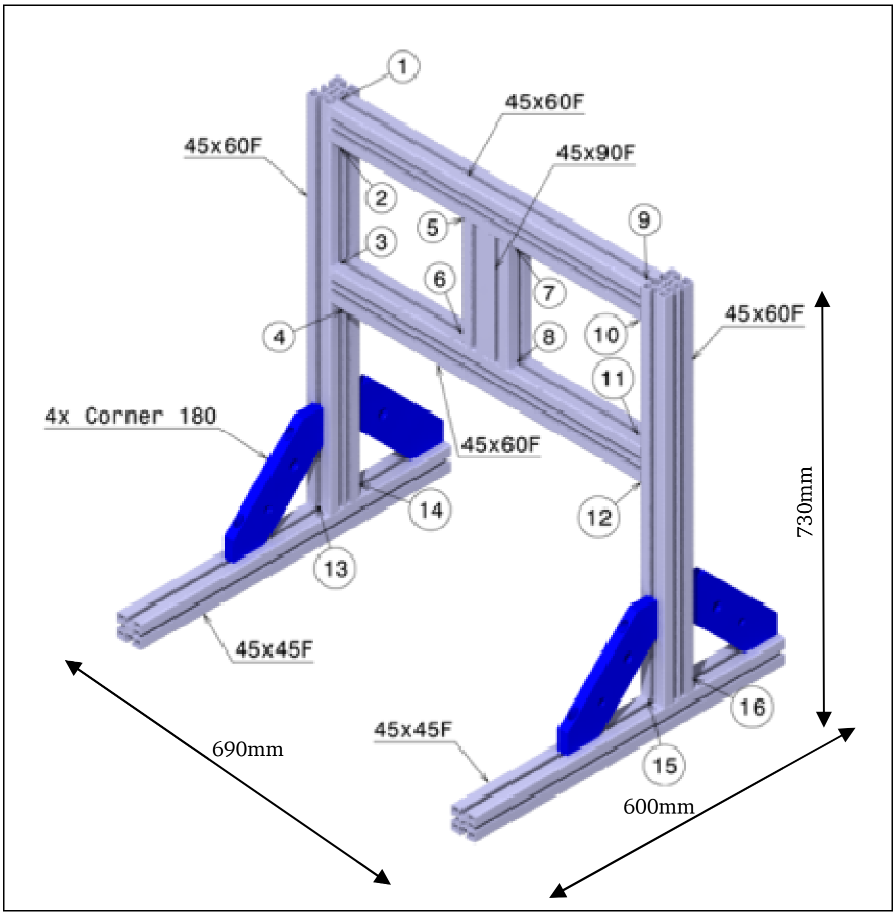


Figure 4-32: Structure final design

The fixations between profiles have been done with power-lock fasteners. This fastener is an extremely strong element able to resist the torques and the shear stress at the structure fixations. Moreover, it simplifies the fixation between profiles thanks to its easy assembly and is subsequently easily adjustable. The fastener is screwed by hand into the end of the profile 1; the second profile is placed at the required position, and finally the set-screw M8 is tightened with hexagon key with T-handle (See Figure 4-33). This fastener has been used in both sides of the profile end to be fixed (all the connections with power-lock fasteners are numbered in Figure 4-32).

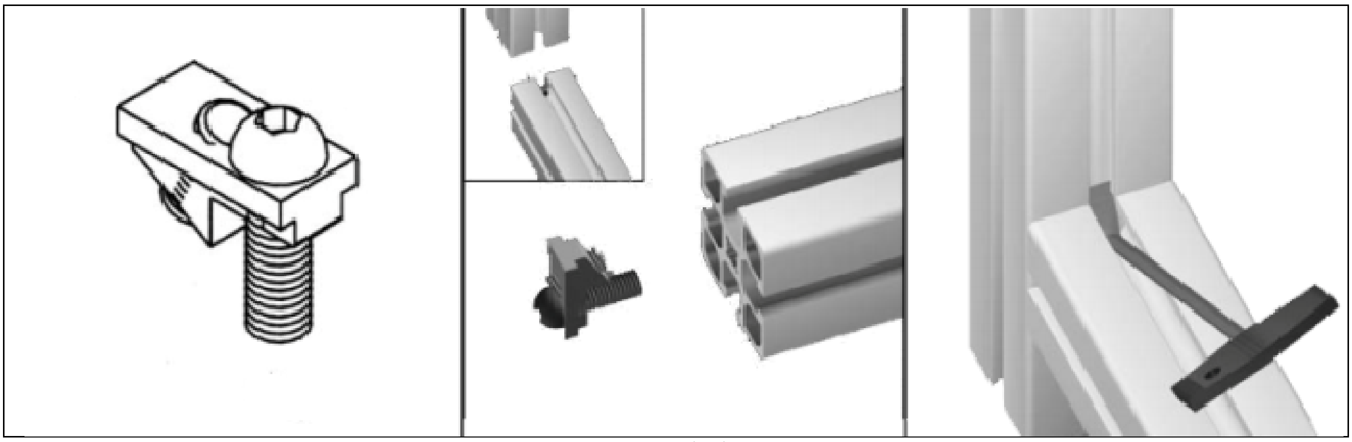


Figure 4-33: Power-lock fastener [16]

Furthermore, 4 Corners 180 (blue coloured in Figure 4-32) are used to compensate the torque caused by the application of the force in a plane parallel from the structure midplane (See Figure 4-34).

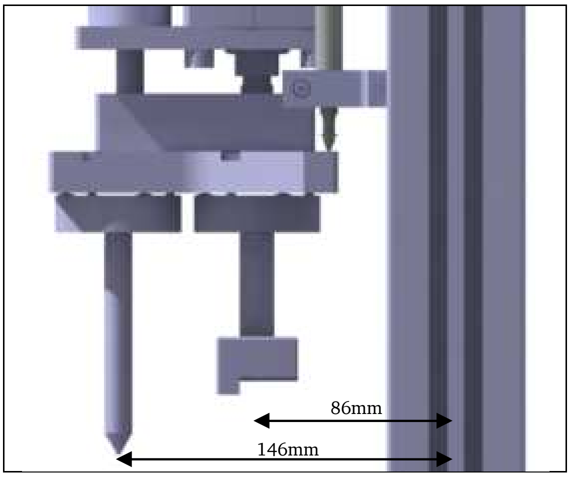


Figure 4-34: Distance between force aplication plane and the structure midplane

In order to check the final structure design, ESTRUWIN software has been used. ESTRUWIN is an application for flat structures calculation using matrix methods, developed by the School of Industrial Engineering of Barcelona (ETSEIB-UPC).

Two critical load cases are going to be analyzed.

The first one (See Figure 4-35) is the maximum load case for the pins test. In this case, the structure receives from the actuator a 450N upward vertical reaction force. Other forces that have to be taken into account are the weight of the components fixed to the structure (54N aprox.) and the dead weight (the weight of each beam).

The second one (See Figure 4-36) is the worst load case that the structure may suffer. In the future it is possible that a test of pulling the pins of the connector would be performed. In this case, the structure receives from the actuator a 450N downward vertical reaction force. Other forces that have to be taken into account are the weight of the components fixed to the structure (54N aprox.) and the dead weight (the weight of each beam).

After defining the beams (section, dimensions, specific weight and fixation of the ends) in the SRTRUWIN software, the external loads (reaction force of the actuator and weight of the components fixed to the structure) are also defined. Then the analyses are performed. The reactions of the floor, the bending torque and the deflection diagrams of both cases are shown in Figures from Figure 4-37 to Figure 4-42.

The stress and torque of each joint are less than the resistance of the power-lock fastener used in each connection. The power-lock fastener can withstand a static load of 6000N. Therefore it is not necessary to use extra fixation elements to strength the profile connections.

The maximum deflection, 23,5µm, happens at the maximum force in the pins pulling test. This deflection is not critical because the displacement measurement is not required for this kind of test. The displacement measurement is only required in the buttons test and, as it is checked in the Equation 2, the maximum force applied for this test, 10N, causes a deflection of 0,5µm. This deflection is negligible compared to the tolerances of the displacement to be verified. The weight of the components fixed to the structure is not included in this calculation since the deflection caused by this weight is constant, it is the same before the button is pressed than when the force applied to the button is the maximum. Thus, the deflection due to the weight of the components fixed to the structure does not influence the measurement of the button displacement.

$$f = \frac{F*l^3}{192*E*I} = \frac{10*600^3}{192*70.000*32,07*10^4} = 0,0005mm$$

Equation 2: Maximum deflection in Buttons test [15]

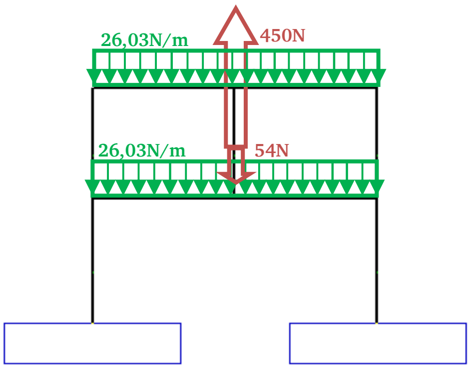


Figure 4-35: Load case of the Pins pushing test

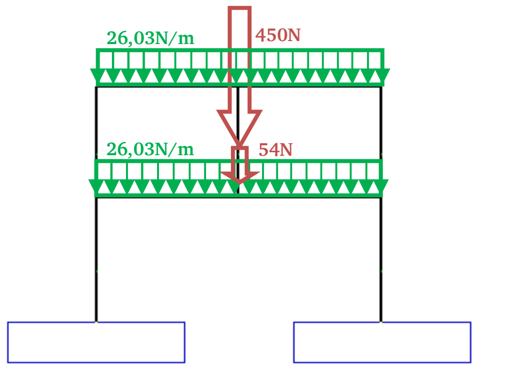


Figure 4-36: Load case of Pins pulling test

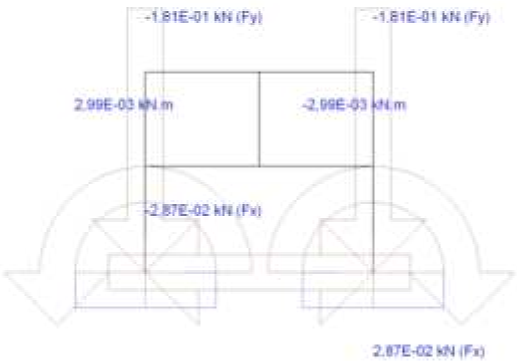


Figure 4-37: Reactions diagram of Pins pushing test

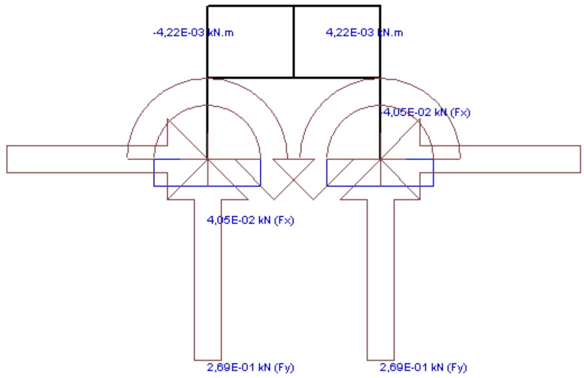


Figure 4-38: Reactions diagram of pins pulling test

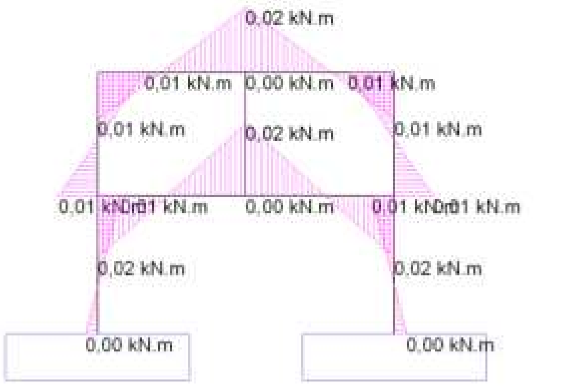


Figure 4-39: Bending torque diagram of Pins pushing test

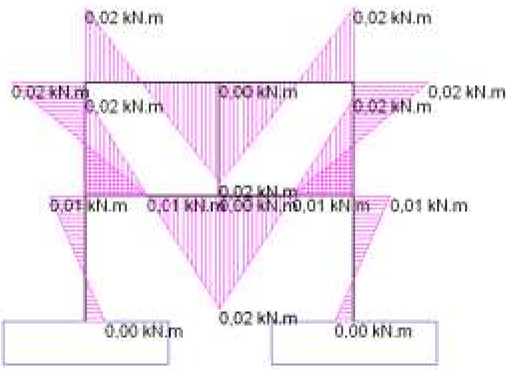


Figure 4-40: Bending torque diagram of Pins pulling test

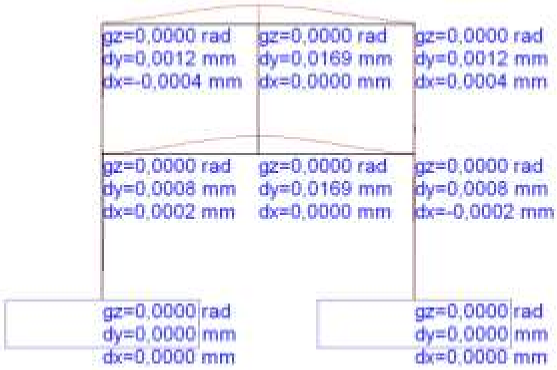


Figure 4-41: Deflection diagram of Pins pushing test

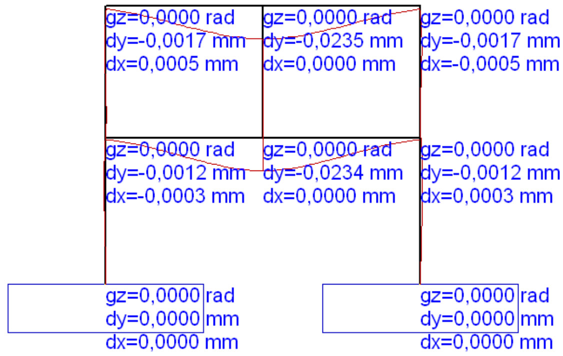


Figure 4-42: Deflection diagram of Pins pulling test

4.5.3. Non-commercial parts design

30 parts have been designed because there were not any commercial parts that can fulfil their requirements. These parts have been designed using CATIA and the drawings have been sent to Schoder GmbH, a manufacturing company specialized in metal processing.

In the Appendix C all the drawings of the parts sent to be manufactured are shown. The order of the parts is due the priority to be manufactured. The manufacture company could not finish all parts before three weeks. For this reason, the parts were divided in four groups in order to get each group as soon as it would be manufactured and could assemble the device as soon as possible.

As is shown in the Appendix C, the material of the load cell ends for the button test and the pin test and of the Load cell end connection is steel S235JR (See Table 4-20). The components rest are made of aluminium EN AW-2007 (See Table 4-21). These materials have the suitable properties that are required by each part designed.

Metal	Tensile strength Rm [MPa]	Yiel strength Re [MPa] for thickness	
		≤ 16mm	>16mm U ≤40mm
S235JR	340...470	235	225

Table 4-20: S235JR mechanical properties DIN EN 10025 [17]

Metal	Tensile strength Rm [MPa]	Yiel strength for thickness ≤ 30mm
		Re [MPa]
EN AW-2007	≥370	≥240

Table 4-21: EN AW-2007 mechanical properties DIN EN 752-2 [17]

The general manufacturing tolerances used are according to the ISO 2768-m and the dimensions of the holes for the screws are according to the DIN EN 20273 and the DIN 974. All this standards are summarized in the *Tabellenbuch Metall* [17].

All parts are made from a block or a bar using machining processes. The principal machining process used is the milling process. In this process, a rotating tool with multiple cutting edges is slowly moved relative to the material to generate a plane or straight surface. The direction of the feed motion is perpendicular to the tool's axis of rotation. Two basic forms of milling are the peripheral milling and the face milling [18].

Detailed bellow is a list of some justifications about the design of the most important parts.

4.5.3.1. Table

The table is an aluminium block of 20mm thick with four holed guides, for the clamps' fixation, and eight counterbored holes, for screw the device structure's feet. The length and position of the holed guides are according to the position of all infotainment system models to be tested. The table provide a stable test device's foundation and ease fixation of the infotainment system to be tested.

4.5.3.2. Force sensors’ fixation

	The force sensors’ fixation is an aluminium block with six counterbored holes, for its fixation to the actuator head, and six holes more, for the fixation of the load cells. There are six linear holes in order to introduce the nuts and fixate the load cells when the force sensors’ fixation is already screwed to the actuator head. The 500N load cell axis is aligned to the actuator axis to avoid high bending torque when the maximum force of 450N is applied. This part is designed with this shape because it supports the end of the digital indicator in order to measure the displacement of the actuator.

4.5.3.3. Digital indicator fixation

	The digital indicator fixation consists of two pieces. These parts have a rib with narrow tolerances for a tight assembly to the profile. These parts are assembled with 2mm gap, creating an Ø8mm H8 hole for the fixation of the digital indicator. The two parts are screwed to make the fixation safer.

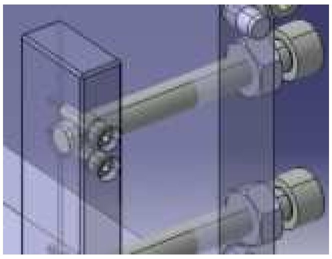
4.5.3.4. Load cell ends for button test and pin test

	The load cell ends for the button test and the pin test are made of steel to be screwed correctly to the load cells. The requirement of fixating 10cm cable length for the cable and plug test causes that the ends here described need to be 97mm and 85mm long, respectively, in order to sweep all infotainment systems’ height.

4.5.3.5. Infotainment System fixation

	The infotainment system fixation consists of seven aluminium pieces. In the front and lateral sides (part numbers 1, 2 and 5, respectively, see Radio fixation assembly drawing in Appendix C), lineal holes have been machined for tight guiding all infotainment systems models and improve its fixation. Some holes are made in the bottom side in order to could perform the pins connector test and to improve the stability of the infotainment system fixed. All sides of this metal box are assembled using M8 screws DIN912 and Ø8 dowel pins DIN7. The clamping system is described in the section 4.5.3.6. For performing the pins connector tests, the feet (See 4.5.3.8 section) are assembled on the Infotainment System fixation. Four threaded holes has mechanized on the lateral sides in order to screw the CDR31 infotainment systems models to secure them when they are faced down at pins connector tests.

4.5.3.6. Clamping system for the Infotainment System fixation



The clamping system consists of one aluminium block fixed to two M10 “screw guides” by means of four M4 screws DIN912. The screw guide (See see drawing 14 in Appendix C) is a DIN912 M10x80 screw mechanized with a circular groove in its end. This mechanization allows screwing or unscrewing the “screw guide” to the back side of the metal box moving forward or backward the aluminium block.

4.5.3.7. MIB spacer

MIB is an infotainment system model with a lower depth than the other infotainment system models. Because of that, MIB model needs spacers to be fixated.

4.5.3.8. Infotainment System fixation’s feet

The feet of the infotainment system fixation consists of five aluminium blocks. These blocks are assembled using M8 screws DIN912 and Ø8 dowel pins DIN7. Three ribs at each food hold the blocks at right angle to increase the assembly resistance. Moreover, four threaded rods are used to avoid the feet to move away by applying a high force. Two of the threaded rods are also a passive security system to fixate the DC-212 infotainment system model when it is faced down at pins connector tests.

4.5.3.9. Clamp fixation

Four clamps fixation have been manufactured in order to adjust the clamps linearly within the guides of the table.

4.5.3.10. CDR31 spacer

	CDR31 is an infotainment system model with three variants. One of them is higher than the others. Therefore, it is need two spacers to fixate this variant properly to the infotainment system fixation.

4.5.3.11. Load cell end cable fixation

	The load cell end cable fixation is the end used in the Cable and Plug tests. The one in the figure is an old design that was manufactured by mistake. This is one piece made of steel. The final design of this end is defined in the corresponding drawing in the Appendix C. In order to design a cheaper piece, the load cell end of the final design is made of aluminium and has a hole to screw the end to the load cell with a DIN7984 M8 screw.

4.5.3.12. Load cell ends for plug test

	For the plug test, two different tools have been developed because the male connector of the MIB infotainment system model is different from the male connector of the other infotainment system models. The load cell end for plug test consists of one aluminium block, mechanized with the negative shape of the male connector, and one steel bar, called Load cell end connection, to fixate the aluminium block to the load cell.

4.6. Application Programming Interface (API) development

Besides designing and assembling the test device, the software to control and obtain the results of the Button test has also been developed. Due to time limitations, only the Button test has been programmed. The other four tests are based on the programming of the Button test. It is only needed to modifying certain control parameters and changing the results that are going to be shown. The software of the Pins connector test is going to be developed soon.

The Application Programming Interface has been developed using LabVIEW [19]. LabVIEW is a platform and development environment for a visual programming language from National Instruments. The purpose of such programming is automating the usage of processing and measuring equipment in any laboratory setup. LabVIEW programs are called virtual instruments (VIs). Each VI has two components: a block diagram and a front panel. Controls and indicators on the front panel allow the user to input data into or extract data from a running virtual instrument. The block diagram is where the API is programmed. Functions from the LabVIEW libraries or functions developed by the programmer are connected and interact between them. In this way, simpler functions are created in order to develop a general and harder VI. This procedure is the same as the one in the section 4.2 used to design the test device.

The main VI has developed using a sequence structure to ensure that the phases are executed one after the other. These phases are: open the COM-Ports of the sensors and the actuator; calibrate the force sensor; perform the test and close the COM-Ports.

The Block diagrams of the main VI and of the Sub-VI's are shown in the Appendix D.

All phases of the main VI for the Button test are described below:

1. **Open the COM-Ports of the sensors and the actuator:**
   The two force sensors, the displacement sensor and the actuator are connected by means USB connectors to the computer. To enable the connexion and the data communication between these devices and the computer, to open the Communication Ports is necessary.
   Only one force sensor is used to perform the test, because of that, before calibrating the force sensor, it is checked whether the sensor connected is the suitable one.
   In this phase, the local variables are also initialised.
   The transmission parameters of each device are shown in Table 4-22.

Device	Default COM-Port	Baud rate [bps]	Bit length [bits]	Parity	Stop bits [bits]	Flow Control
Actuator	COM 4	115200	8	None	1	None
Displacement sensor	COM 3	4800	7	Even	2	None
20N force sensor	COM 5	115200	8	None	1	None
500N force sensor	COM 6	115200	8	None	1	None

Table 4-22: Device's transmission parameters

2. **Calibrate the force sensor**
   Each load cell end has different weight; consequently, each time a test is going to be performed, the force sensor is calibrated in order to tare the weight of the load cell end.

3. **Perform the test**
   Measurements from the displacement and the force sensors are read constantly. These actions are performed using two While Loop structures, which repeat the subdiagram inside it until the test finish. The subdiagram is repeated each period of time defined by the programmer. The minimum period of time to read the measure of the displacement sensor is 300ms. However, period of data acquisition of the force sensor is 0,4ms. The force data refresh is critical, because the force sensor is the device that sends a signal to stop the actuator when the maximum force would be detected. In the case of the button test, the force increase quickly after pressing the button. For this reason, the time rate of the while loop to read the data from the force sensor should be the minimum. In contrast, if the while loop's time rate is too low, the CPU would collapse. Therefore, the while loop's time rate of the force sensor data acquisition has been fixed to 25ms. The force measurement subdiagram check constantly whether there is contact between the load cell end and the button or whether the force applied is equal or higher than the maximum force defined. The procedure of the test is described below.
   a) The number of the button to be tested is shown in order to place the infotainment system in the suitable position.
   b) The stroke of the actuator is defined in order to adjust the load cell end as near as possible to the button to be tested and the infotainment system is placed accurately in the suitable position.
   c) Then the button test starts pushing automatically the buttons until the maximum force is applied. During the test, the front panel shows the force and stroke data in a graph.
   d) After performing the test, the data obtained are processed to get the results required. This data processing consist of:
      - Show a smoother graph of the force-stroke button's characteristic. Due to the fact that the displacement sensor acquire data each 300ms, it is necessary to interpolate these data in order to obtain a data pair (force,stroke) each 25ms.
      - Check whether the data obtained are within their required ranges of tolerances.
      - Save the data obtained in a spreadsheet and the image of the front panel's results.
   e) When the button has been tested, there are three possibilities: repeat the test with the same button, test the next button or finish the test.
4. **Close the COM-Ports**
   In order to be able to open the COM-Ports in following tests, these must be closed correctly. Moreover, the errors of each device are read.

For the proper running of the software and for avoiding damages of the infotainment system tested or of the test device, some security systems have been programmed. The most important security system programmed is the one that check continuously whether the force applied is equal or higher than the maximum force defined. If the result is positive, the actuator is stopped and it returns to its initial position. Another security system programmed is to stop the actuator and return it to its home position whether an error occurs or the Stop button in the front panel is pressed. Moreover, if there is any data after the test performance, the data processing is stopped and a window appears advising about error and asking what is wished to do next (repeat the test with the same button, test the next button or finish the test).

After programming the API, it is compiled to obtain an executable program that the operator of the test device will use.

All the VI’s and Sub-VI’s developed to perform the button test are listed below:

1. BUTTON_TEST_F1_S2_SNAP
2. BUTTON_TEST_F1_F1-F2_S1_S2-S1
3. Initialize the actuator (INIT ACT)
4. Read stroke (READ STROKE)
5. Activate or deactivate the actuator’s servo (SON)
6. Return the actuator to its home position (HOME)
7. Stop the actuator (STOP)
8. Read the position of the actuator (READ POS)
9. Move the actuator up to the defined displacement increment (UP MOVE)
10. Move the actuator down to the defined displacement increment (DOWN MOVE)
11. Move the actuator to the target position defined (TARGET POS)
12. Press the button moving the actuator at 0,08mm/s (BUTTON MOVE)
13. Interpolate the displacement data (INTERPOLE)
14. Detect the force at the actuation point (See Figure 2-2) (DETECT PEAK)
15. Detect the force at the snap point (See Figure 2-2) (DETECT VALLEY)
16. Check whether the value measured is within the required tolerances (IN TOL)
17. Show force sensor’s error message (MESS ERROR)
18. Read actuator’s alarm (READ ALARM)
19. Show actuator’s alarm message (MESS ALARM)
20. Reset actuator’s alarm (ALRS)

5. IMPLEMENTATION

5.1. Assembly

In order to assemble properly the test device, a specific assembly sequence must be followed. These steps are the following:

1. Place the clamps fixations in their suitable test device table's guides below the table.
2. Fixate the four clamps using eight DIN912 screws M4x12 and eight DIN555 nuts M4.
3. Screw the structure feet to the table using eight DIN7984 screws M8x25 and eight square nuts M8 with position-fixing (from Minitec). Do not fixate them completely in order to adjust them when the structure rest will be assembled.
4. Screw all the power-lock fasteners into the end of the appropriate profiles. Previously, the threads have been processed by using a thread former. Each pillar has two power-lock fasteners screwed into the lower end; each lintel, two fasteners more into each end and the central pillar, two fasteners more into each end.
5. Introduce the power-lock fasteners of the central pillar inside the T-guides of the upper and lower lintels. Do not tighten the fasteners in order to move freely the central pillar.
6. Introduce the power-lock fasteners of the lintels' right ends inside the T-guide of the right pillar. Do not tighten the fasteners in order to move freely the lintels.
7. Introduce the power-lock fasteners of the lintels' left ends inside the T-guide of the left pillar. Do not tighten the fasteners in order to move freely the lintels.
8. Adjust measures between profiles by using a calibrated metal ruler and a rubber hammer.
9. Tighten all twelve power-lock fasteners to fixate all profiles between themselves.
10. Introduce the power-lock fasteners of the pillars lower ends inside the T-guides of the structure's feet. Adjust specific measures and tighten the fasteners.
11. Adjust finally the structure's feet to the table limits and tighten the eight screws.
12. Adjust and fixate the four Corners 180 by using their fixation kit.
13. Check the horizontalness of the profiles by using a Spirit level. To adjust the horizontalness of a profile, loosen the corresponding fasteners, adjust the profile position by using a rubber hammer and tighten again the fasteners.
14. Screw the actuator fixation to the central pillar, by using four DIN7984 screws M8x20 and four nuts M8 with position-fixing (from Minitec). Taking into account the defined distance between the actuator fixation lower side and the upper side of the lower lintel. Before tighten completely, check the horizontalness of the actuator fixation.
15. Screw the force sensors fixation to the actuator's head using six DIN7984 screws M6x25.
16. Fixate the actuator's feet to the actuator's guides using four DIN912 screws M6x12 10.9 and four DIN557 square nuts M6 10. Adjust the defined position.
17. Screw the actuator's feet to the actuator's fixation using four DIN7984 screws M8x25, four DIN436 square washers 8 and four DIN557 square nuts M8. Adjust the horizontalness by using the Spirit level.
18. Screw the two load cells to their fixation using three DIN912 screws M4x30 and three DIN557 square nuts M4, for each one. The 500N load cell is placed in the nearest position to the structure, and the 20N load cell, in the farthest position to the structure.
19. Screw the digital indicator fixation into the upper T-guide of the lower lintel at the specified distance using two DIN7984 screws M6x16 and two nuts M6 with position-fixing (from Minitec). Use a 2mm thickness calibrated plate to define the correct distance between the two parts of the fixation and use the spirit level to check their horizontalness.
20. Fixate the digital indicator through its fixation and tighten the DIN912 screw M4x12 to close the fixation.
21. Cover the profiles ends with the end caps using a rubber hammer.
22. Fixate the cable clips.
23. Fixate the cables to the cable clips using cable straps. Let enough free cable length of the load cells to avoid damaging them when the actuator moves to the final position.

24. Connect the actuator's cable to its controller and connect the controller to the power supply. Connect to the computer all USB connectors of the load cells, the digital indicator and the actuator's controller.

The infotainment system fixation and its feet were assembled by the manufacturer company.

The special nuts with position fixing from Minitec are very useful. This kind of nut has a spring metal that keeps the nut in the desired position and moveable by screw-driver.

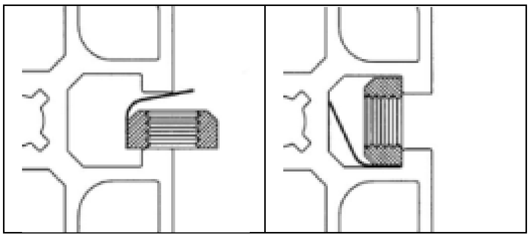


Figure 5-1: Nut with position-fixing assembly [16]

The screws have been tightened using a torque wrench (Figure 5-2) adjusting the maximum torque that the screw can bear.

Figure 5-2: Torque wrench

For tightening the power-lock fasteners, the torque recommended by the supplier has been used, 12Nm.

For the other screws, the following calculations have been carried out taking into account the formulas and explanations from the books "Schrauben-Verbindungen" [20] and "Bolted joints" [21].

By tightening the screw joint an equivalent stress σ_e in the critical cross section of the thread exists from the initial pre-load and torsional stress τ due to the applied torque. The Von-Mises equivalent stress for combined tensile and torsional stress, $\sigma_e=(\sigma_t^2+3\tau^2)^{½}$, may not exceed the yield strength $R_{p0.2}$. For a standard thread and a common coefficient of friction $\mu=0,15$, it is only needed to calculate the screw for tensile stress and a torsional factor of 1,35 is added for taking into account the torsional stress. The calculus methodology of maximum tightening torque is shown in Equation 1.

i. Permissible stress

$$\sigma_{adm} = \frac{R_{p0,2}}{1,4} \qquad (Safety\ factor = 1,4)$$

$$\sigma \leq \frac{\sigma_{adm}}{1,35} \qquad (Torsional\ factor = 1,35)$$

ii. Assembly force

$$F_{Mmax} = \sigma * A_T \qquad (A_T\ is\ the\ total\ resistance\ section)$$

iii. Tightening torque

$$M_A = F_{Mmax} * K * d$$

$$K = \frac{0,16 * P + 0,58 * \mu_G * d_2 + 0,5 * \mu_k * D_{Km}}{d}$$

$$For\ standard\ thread: \qquad K = 0,02222 + 0,528\mu_G + 0,668\mu_k$$

$$Common\ friction\ coeficient: \quad \mu_G = \mu_k = 0,15$$

$$K = 0,2$$

Equation 3: Calculus methodology of maximum tightening torque [20, 21]

The results of these calculations for each screw type are shown in Table 5-1.

Screw quality	Metric	F_{Mmax} [kN]	M_A [Nm]
8.8	M4	2,97	2,38
	M6	6,81	8,17
	M8	12,39	19,83
10.9	M6	9,57	11,48

Table 5-1: Maximum tightening torque values

5.2. Manual of operation of the Button test

In this section, the procedure for performing the buttons test is explained step by step.

1. First of all, check that the USB-Ports from the digital indicator, the load cell required and the actuator controller are connected to the computer and place and tight correctly the infotainment system inside its fixation.
2. Then, turn on the computer. Any Panasonic employee can access to the computer with its own user and password. When the computer is turned on, the digital indicator turns on automatically.
3. Next, turned on the 25V DC power supply. Check that the monitor LED [SV/ALM] of the actuator's controller illuminates for two seconds and then goes out. When an alarm generates, the monitor LED [SV/ALM] illuminates in red.
4. After that, the Button test can be run. Double click to the icon of "BUTTON_TEST_F1_F2_SNAP.exe"
5. The Front panel window appears.

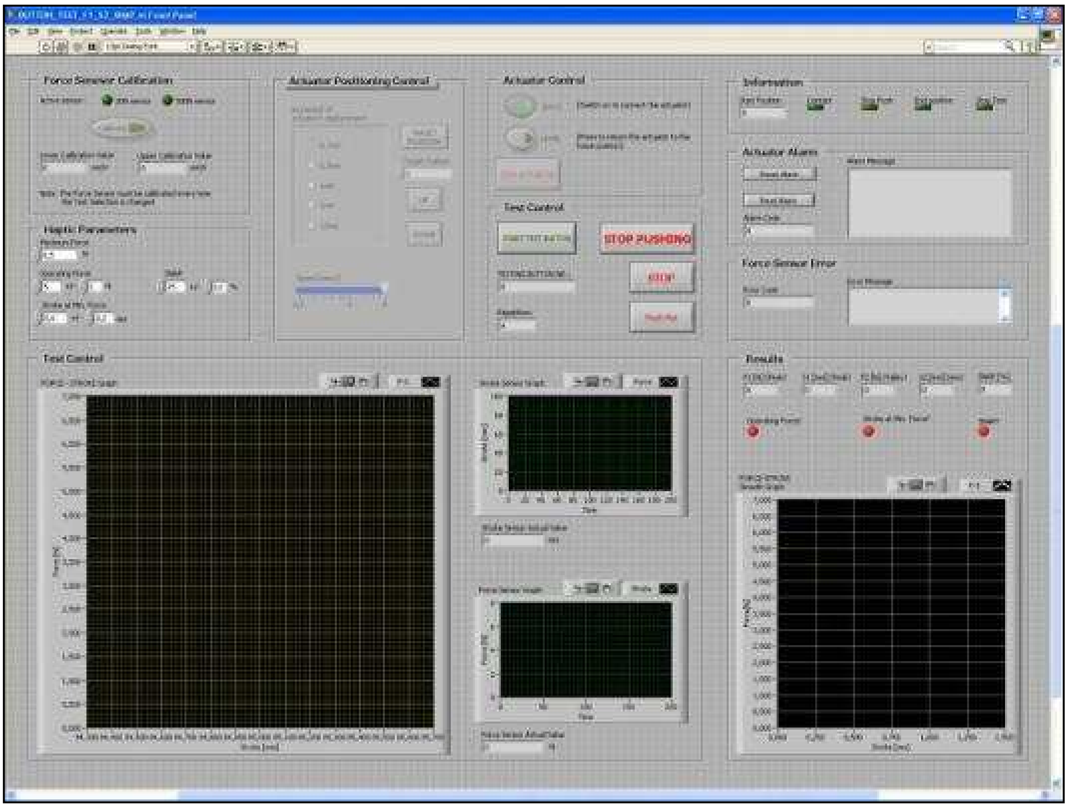


Figure 5-3: Button test aplication interface front panel

6. Press the little white arrow on the upper left corner to run the software.
7. Then, the Force sensor calibration block in the Front panel is activated and a light turns on indicating the sensor that is connected. Moreover, a window appears asking to "Adjust the suitable end to the load cell connected and then press Calibrate button".

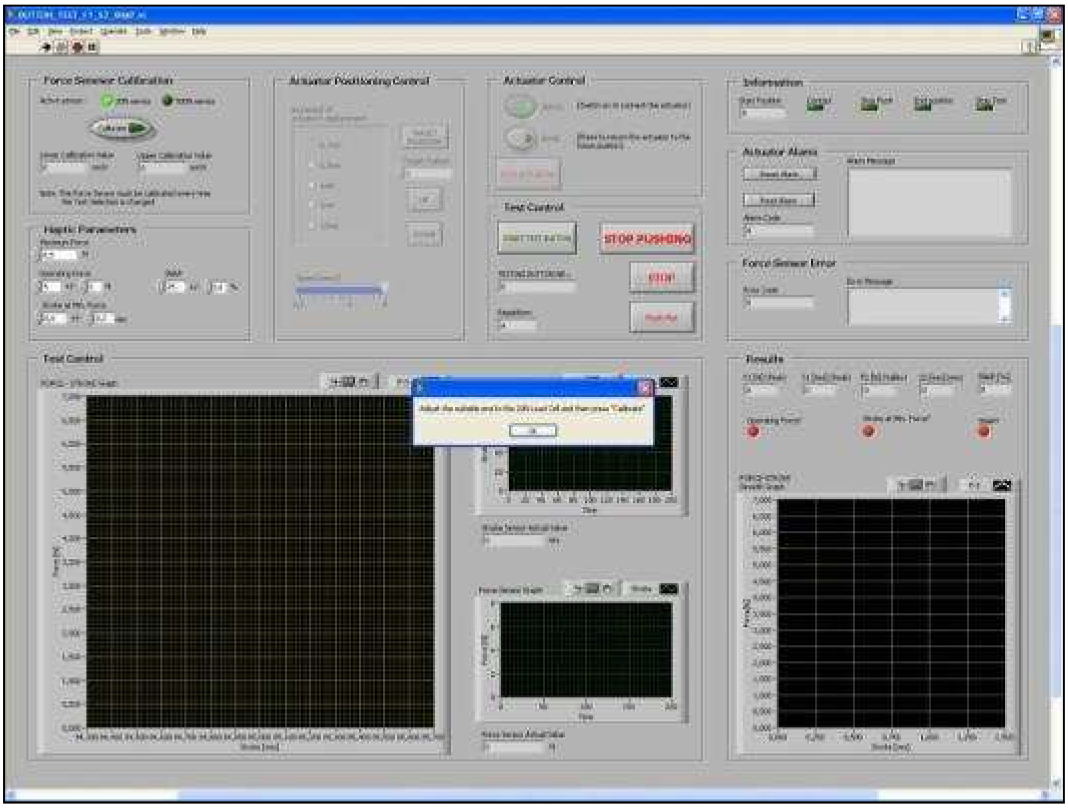


Figure 5-4: Asking to calibrate the force sensor

8. Press OK, adjust the suitable end to the indicated load cell. Be sure that the load cell is the appropriate to perform the test.
9. Press Calibrate button.
10. The calibration values are indicated and the Force sensor calibration block turns disabled and grayed out.
11. Subsequently, the graphs of the stroke sensor and of the force sensor start to show the data obtained in real time.
12. A window appears asking to "Place the Infotainment System in the suitable place in order to test the Button Nr. 1. Adjust the end of the load cell near the button using the 'Actuator Position Control' and then press the 'Start Test Button".

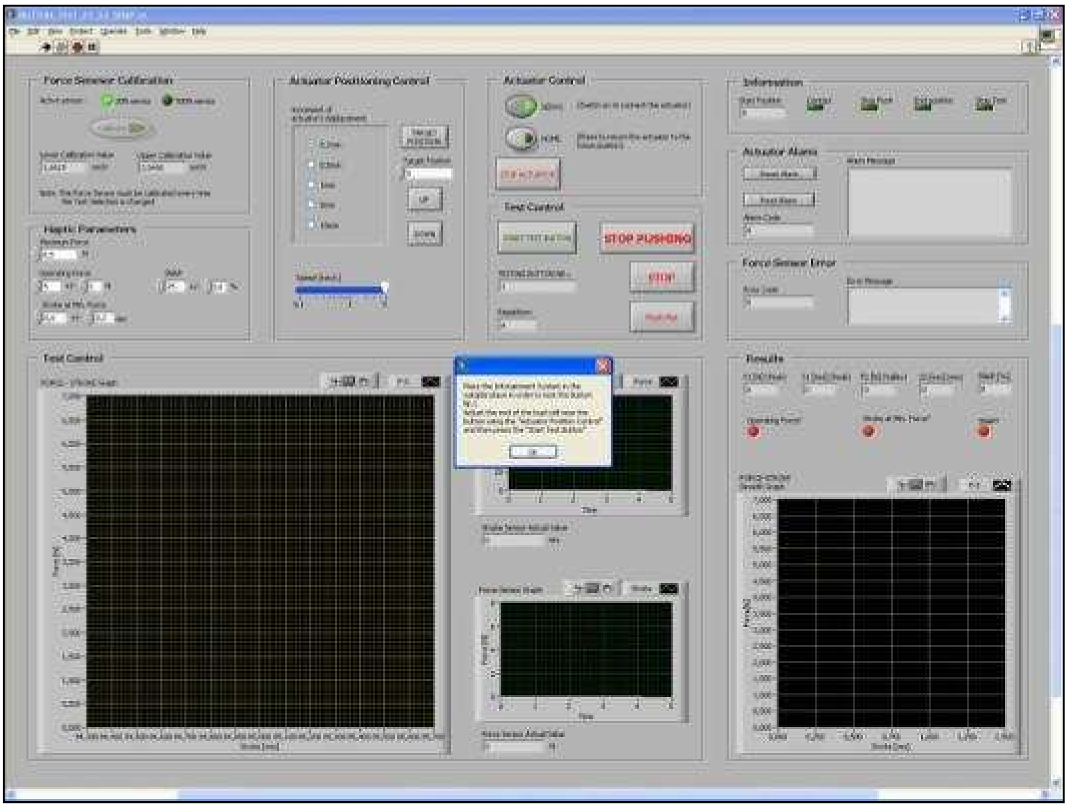


Figure 5-5: Asking to place the infotainment system in the suitable position

13. Press OK. Then the Servo of the actuator is activated producing a thump, the actuator's head move to its home position and the Actuator Positioning Control block is activated. **Before placing the infotainment system**, check that the Haptic Parameters default values are right or modify them to the required ones.
14. Place the infotainment system with its fixation in the suitable place to test the button number indicated.
15. Move the actuator head until the load cell end almost touch the button and adjust correctly the infotainment system position to press the button on the right place.
    - The Actuator positioning control allows moving the actuator's head to a target position, writing a value from 0 to 100mm and pressing the Target Position button. It is also possible to move the actuator's head up or down the displacement increment desired by selecting the increment value and pressing the Up or Down button. A speed control is also implemented.
    - If it is needed to stop the actuator when its head is moving to a certain position, press the Stop Actuator button.
    - If it is needed to return the actuator's head to its home position, press the Home button. Avoid pressing any button during the Home actuator operation, except Stop Actuator button in case needed.
    - When the load cell end touch the button, the light of the Contact indicator at the Information block is turned on.
    - In the case that, by an error, the button is pressed during the actuator positioning task, when the force applied exceed the maximum force defined in the Haptic Parameters block, the actuator head moves to its home position automatically.
16. After placing the load cell end near to the button to be tested, press Start Test Button button, in the Test Control block.
17. Then, a window appears warning that "The test is going to start". Press OK.

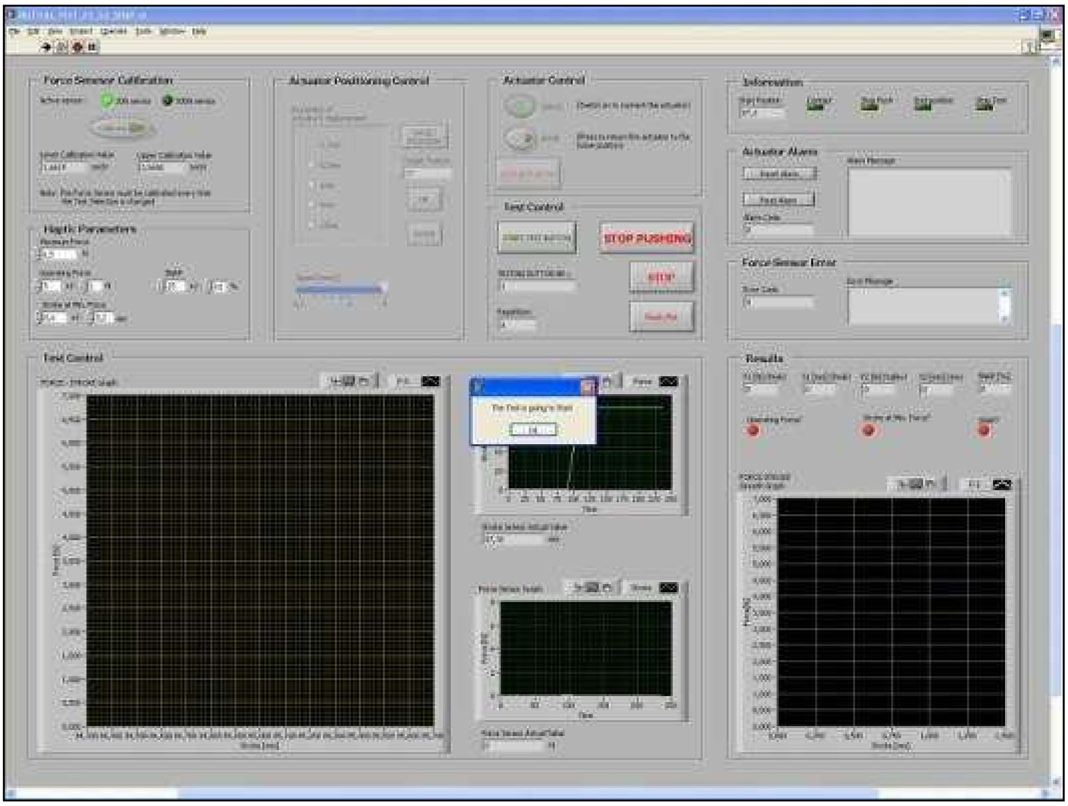


Figure 5-6: The test is going to start

18. In that moment, the test of the button starts and the load cell end press the button at 0,08mm/s. The data obtained from the digital indicator and from the load cell is shown in real time and combined in the Force-Stroke Graph.

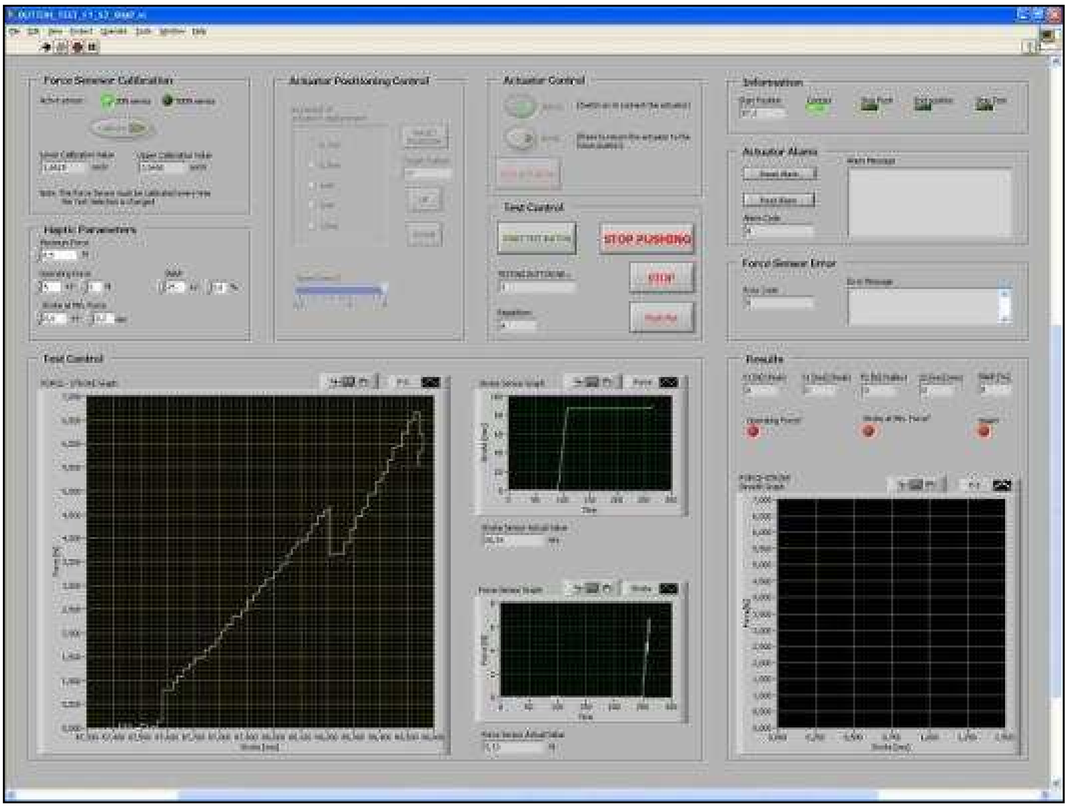


Figure 5-7: Button test performance

19. When the test of the button is already performed, the results are shown in the Results block of the Front Panel, an image of the results is saved automatically with the button's name and the test's repetition in the 'C:\BUTTON TEST\IMAGES\' folder and all numerical data, included the results and graph values, is also saved with the same name as the image in the 'C:\BUTTON TEST\GRAPH DATA\' folder.

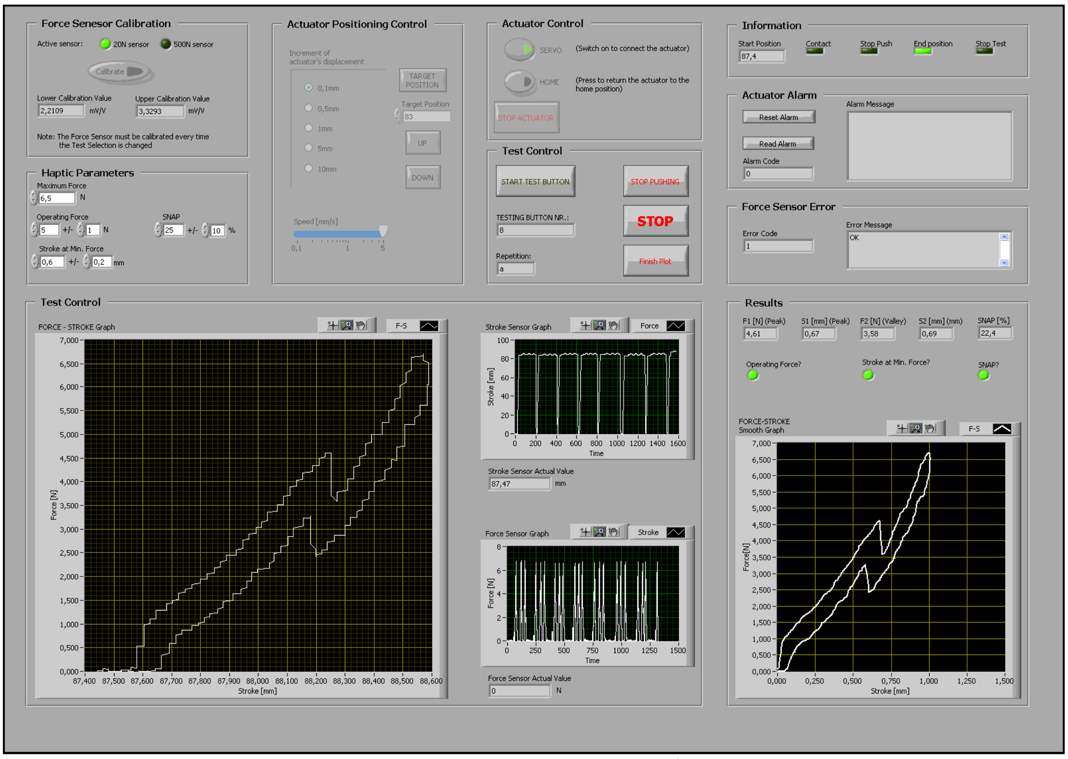


Figure 5-8: Button test results

20. Then, a window appears asking to choose an option: "Test the same button, Test the next button or Finish the button test".
    a) By choosing to "Test the same button", another repetition of testing the same button is going to perform. The Repetition indicator increase in one and the test procedure starts again from the task number 17.
    b) By choosing to "Test the next button", the Testing button Nr. Indicator increase in one, the Repetition indicator get the initial value 'a' and the test procedure starts again from the task number 12.
    c) By choosing to "Finish the button test", the actuator's head returns to its home position, the errors occurred during the test performance are read and, after some seconds, the actuator's servo is turned off, all COM-Ports are closed and the test's software is turned off.

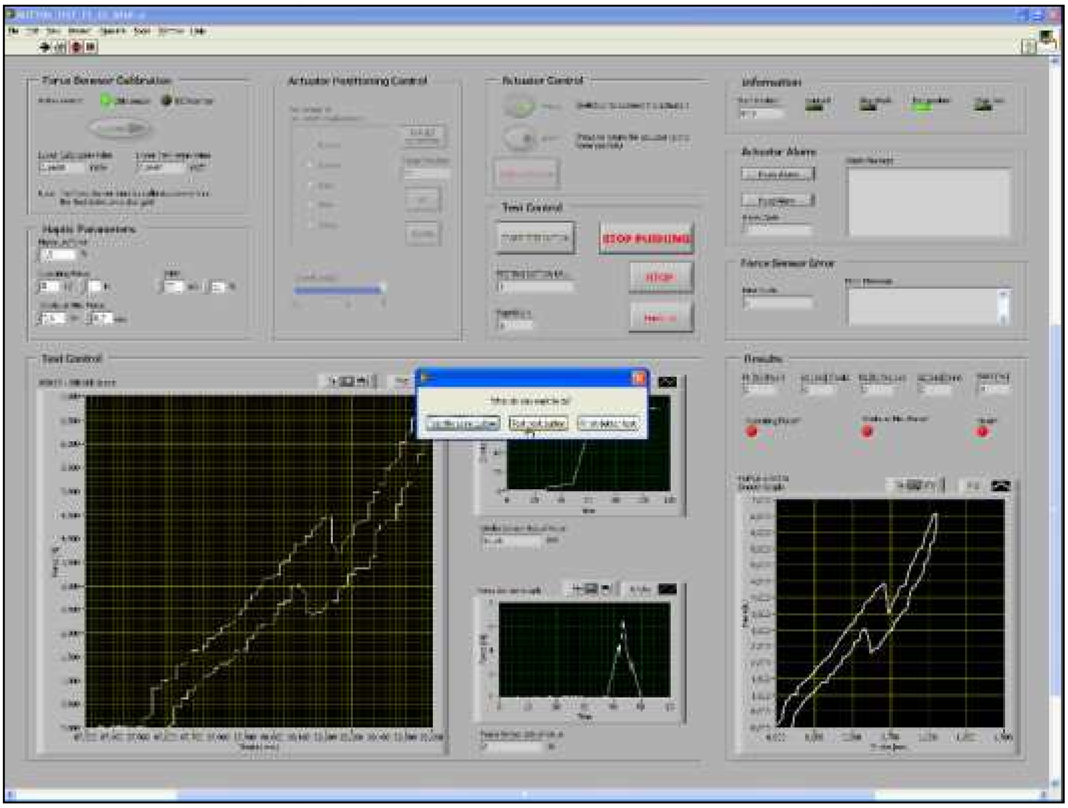


Figure 5-9: Choose between repeating the test with the same button, testing the next button or finishing the test

21. When the test's software is turned off, it is possible to run again the software or close the window.
22. After closing the software's window, cut all the documents created in the folder named in the task 19 and paste them to the desired folder. If the documents are not moved to another folder, the data would overwrite when the software runs again.
23. Turn off the computer and the digital indicator and unscrew the load cell end.

- CAUTION: Be careful and avoid hitting the force sensors and their ends when they are screwed. Its internal properties may change irreversibly.

5.3. Maintenance

The test device requires low maintenance.

It is recommended to tighten all screws after 1week of assembly, after 1month of assembly and every year thereafter due to stress relaxation of the fastening and the device vibrations.

In order to warrant accurate measurements of the sensors, it is recommended to certify the calibration of the digital indicator each 5years and of the load cells, each 3years.

It is recommended to apply grease to the sliding surface of the actuator's rod every 3months and to the ball screw, through the "Grease supply port" at the front side of the actuator, after 3years of operation and every year thereafter.

Over time, the mechanical parts lose quality, resolution and accuracy and do not act like new, but these mechanical parts have no influence on the accuracy and in obtaining accurate data with high resolution because the actuator (the mechanical component degraded over time) is controlled by the sensors that must be calibrated periodically.

6. TEST DEVICE EVALUATION

In order to approve the test device, all demanded requirements have to be fulfilled. Since all demanded requirements have been taken into account to design the device, select the components and develop the software, only the test device performance has to be evaluated.

With the intention of evaluating the test device performance and verifying its technical requirements, repeatability and accuracy tests may be developed.

If the device fails to meet accuracy tolerances, but is able to repeat its results, then a simple adjustment can usually bring the device back within applicable tolerances. If the device fails to meet repeatability tolerances, it may not be possible to use the adjustments on the device to bring it back into a condition where the device consistently performs within tolerance and repeats its results.

6.1. Repeatability evaluation of the test device

Repeatability testing determines whether or not a device is capable of repeating its indications within a certain limit under the same conditions [22].

In order to test the repeatability of the device three random buttons of the CDR31 G1 infotainment system have been tested 26 times each one. The selected buttons are number 4, 11 and 13 (See Figure 6-1).

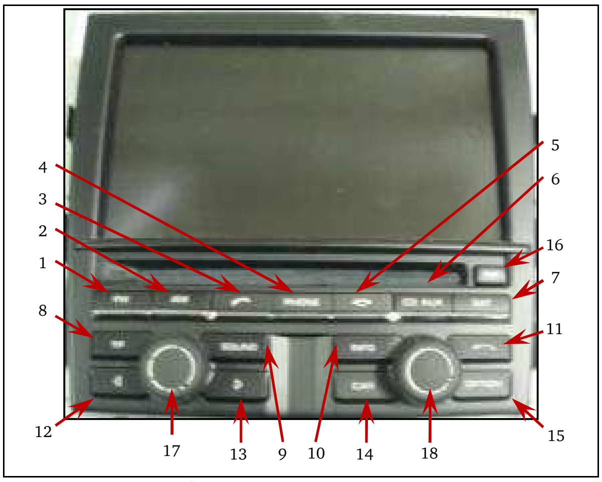


Figure 6-1: Face plate of a CDR31 G1 infotainment system

All parameters' values of the test are shown in Appendix 0. A summary of these results is shown in Table 6-1.

Type	Measurement	Button	Max. Value	Min.Value	Range	Max. Range	Repeatability (=Max.Range/2)
Force [N]	F1	4	4,295	4,246	0,049	0,211	±0.105
		11	4,819	4,753	0,065		
		13	3,906	3,800	0,106		
	F2	4	3,398	3,188	0,211		
		11	3,770	3,665	0,104		
		13	2,999	2,854	0,145		
Stroke [mm]	S1	4	0,743	0,698	0,045	0,058	±0,029
		11	0,735	0,699	0,035		
		13	0,752	0,698	0,054		
	S2	4	0,768	0,727	0,041		
		11	0,761	0,717	0,044		
		13	0,783	0,725	0,058		

Table 6-1: Summary of repeatability test

Taking into account these results and the repeatability requirements, ±0,1N for the force and ±0,05mm for the stroke, it is possible to conclude that the test device fulfil the requirement of displacement repeatability but it does not fulfil the requirement of force repeatability with an error of 5,5%. However, this error is low and the ranges of the other measure series are lower than the force repeatability requirement. Moreover, the measure of 3,398N could be an error due to external factors such as vibrations, sliding of the load cell end on the button, etc. If this maximum value is removed from the obtained data, the F2 range of the button number 4 would be 0,179N. Therefore, the force repeatability value of the test device would be ±0,090N and this value fulfils the force repeatability requirement.

Taking into account the manufacturing tolerances for these characteristics (±1N for the F1 and ±0,2mm for the S1 and S2), the repeatability value of force represents a 10,5% of the force manufacturing tolerance and the repeatability value of stroke represents a 14,5% of the stroke manufacturing tolerances. In accordance with the AIAG (Automotive Industry Action Group) standards for the Repeatability & Reproducibility test, the test device is acceptable if the %Tolerance is less than 20%.

For all these reasons, the test device is validated by repeatability evaluation.

6.2. Accuracy evaluation of the test device

Accuracy testing determines whether or not the device is installed and adjusted to perform within applicable tolerance limits. Failure to meet accuracy requirements typically indicates that the device is not adjusted or installed properly [22].

In order to measure the accuracy of the test device, it is needed the "true value" of the buttons characteristics. These "true values" are obtained by a certification company or a test device already calibrated with a high known accuracy. Panasonic does not have these values yet, consequently, this accuracy evaluation of the test device could not be made correctly.

With the purpose of approximating the range of accuracy of the test device, the measures obtained with the test device have been compared with the ones obtained by a manual test device (See Figure 6-2).

Figure 6-2: Manual force-stroke test device

The 18 buttons of the CDR31 G1 infotainment systems have been tested three times with each method. The rudimentary manual method allows only obtaining the values of F1 (with a resolution of 0,1N) and S2 (with a resolution of 0,01mm), thus, these are the characteristics that are going to be evaluated. The Table 6-2 shows the results.

Button	F1 [N] automatic test device	manual test device	F1 accuracy ± [N]	S2 [mm] automatic test device	manual test device	S2 accuracy ± [mm]
1	4,032	4,1	0,068	0,807	0,82	0,013
2	4,465	4,5	0,035	1,070	1,04	0,030
3	3,968	4,1	0,132	0,937	0,89	0,047
4	4,286	4,6	0,314	0,753	0,72	0,033
5	4,340	4,5	0,160	0,969	0,95	0,019
6	4,324	4,4	0,076	1,060	1,07	0,010
7	4,242	4,5	0,258	0,902	0,87	0,032
8	4,581	4,7	0,119	0,695	0,69	0,005
9	4,675	4,7	0,025	0,832	0,82	0,012
10	4,374	4,5	0,126	0,819	0,80	0,019
11	4,836	4,7	0,136	0,740	0,76	0,020
12	4,085	4,2	0,115	0,839	0,81	0,029
13	3,961	3,9	0,061	0,780	0,76	0,020
14	4,107	4,2	0,093	0,832	0,87	0,038
15	4,419	4,4	0,019	0,797	0,77	0,027
16	7,752	8,0	0,248	0,656	0,63	0,026
17	7,476	7,7	0,224	0,645	0,59	0,055
18	4,944	5,2	0,256	0,839	0,82	0,019
		Max. F1 accuracy	±0,314N		Max. S2 accuracy	±0,055mm

Table 6-2: Summary of the accuracy test

The values of force accuracy and displacement accuracy do not fulfil the requirements but, as mentioned before, these are not the real values of accuracy, and a correlation with the values obtained by a certification company must be done.

To summarize, the test device fulfils the repeatability tolerances but it is needed that a certification company measure the characteristics of the same CDR31 G1 infotainment system tested in order to correlate the both series of data and accomplish the accuracy evaluation of the test device.

7. OUTLOOK

The tasks described below are potential for further improvements:

- Perform the accuracy evaluation of the test device with “true values”.
- Program the software of the pins connector tests.
- The load cell end of the button test slides when the switch actuates. This happens only with few buttons whose surfaces are very smooth. An improvement would be to put a rubber tip at the end tip.
- Integrate the tests’ software in Panasonic Environment (PASTA) to could use the Panasonic database.
- Implementation of another function in the LabVIEW software for detecting the maximum and minimum point by extrapolation of the measurements and intersection of the up and down curve.
- There is the possibility of performing other kind of tests (for instance, buttons’ destruction test) only by changing the parameters of the most similar test (in this case, the pins test), using the suitable end (in this case, the buttons test end) and using the suitable force sensor (in this case, the 500N force sensor).

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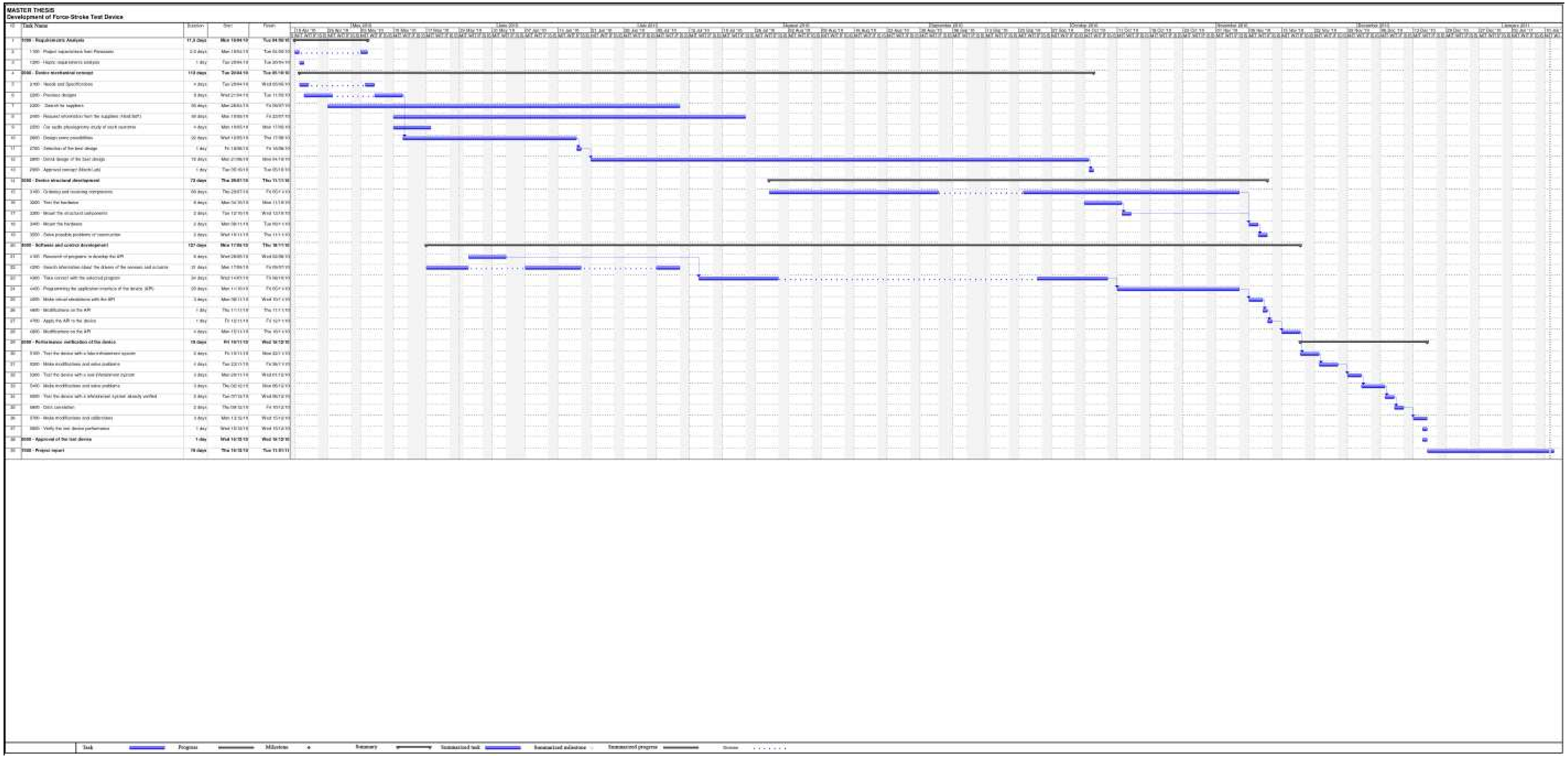
APPENDIX

A. Schedule



B. Components selection

a. Actuator selection

FIRMA	MODEL	PRICE [€]	ACCURACY [µm]	RESOLUTION [mm]	REPEATABILITY [mm]	MAX. FORCE [N]	STROKE [mm]	MOTOR TYPE	POWER SUPPLY	COMMUNICATION INTERFACE	DELIVERY TIME [weeks]	E-MAIL	TELEPHONE	CONTACT PERSON
IAI	RCP2-RGS6C-I-56P-4-100-P1-S-B	960,00	±50	0.01	±0,02	800	100	Step						
	PCON-CG-56PI-PN-2-0 (controller)	170,00							DC24V	USB+Modbus protocol	4	Ripplinger@iai-gmbh.de	+49(0)61968895-16	Leonhard Ripplinger
	RCM-101-USB-EU (cable+softw)	250,00												
		1.380,00												
Aerotech	PRO225-05MM-0150-TTM-5V-NC-BMS-E1000ASH-3-C05	6.445,00	±3	0,0005	±0,001	500	150	Servo			9			
	SOLOISTCP20-IO-MXU (controller)	2.330,00							230VAC	USB+Ethernet				
	Controller Software for LabView	1.370,00												
	AC Line Filter Module	760,00												
	Cables	420,00												
		11.325,00												
Owis	LIMES 170-155-HSM57/PG	7.818,90	±3	0,001	<±0,003	500	155				8			
	Fixation	250,00												
	PS 90-24-240	1.532,80						Step 200						
	LMS-LIMES 170-155 (linear encoder)	1.547,00	±3	0,0001	±0,001									
	AM-3-2SM (drive module for step motor)	2.008,10							DC24V	USB+LabView driver				
		13.156,80												
SKF	LTB110.0230.TN1205-P2/V	2.602,00	±40	0,001	0,01	500	110				6			
	Drive pack AC servo LTB110-2	3.505,00						Servo	230VAC	RS232				
		6.107,00												
~~Thomson~~											~~14~~			

b. Force sensor selection

VARIANT	FIRMA	MODEL	PRICE [€]	ACCURACY ± %	ACCURACY ± [N]	RESOLUTION [N]	MEASURING RANGE [N]	COMMUNICATION INTERFACE	DELIVERY TIME [weeks]	E-MAIL	TELEPHONE	CONTACT PERSON
Force gauge	Alluris (force gauge)	FMI-220B2	795,00	0,20	0,04	0,01	20	RS232C/USB/Analog		info@alluris.de	+49 761 47979 47	Klaus Hartkopf
Force gauge	Alluris (force gauge)	FMI-220C5	795,00	0,20	1,00	0,1	500	RS232C/USB/Analog		info@alluris.de	+49 761 47979 47	Klaus Hartkopf
Force gauge	ATP-Messtechnik	FMI-230B2	1157,00	0,05	0,01	0,001	20	RS232C/USB/Analog		verkauf@atp-messtechnik.de	+49 (0) 7822 8624	
Force gauge	ATP-Messtechnik	FMI-220B2	795,00	0,20	0,04	0,01	20	RS232C/USB/Analog		verkauf@atp-messtechnik.de	+49 (0) 7822 8624	
Force gauge	ATP-Messtechnik	FMI-230C5	1157,00	0,05	0,25	0,01	500	RS232C/USB/Analog		verkauf@atp-messtechnik.de	+49 (0) 7822 8624	
Force gauge	ATP-Messtechnik	FMI-220C5	795,00	0,20	1,00	0,1	500	RS232C/USB/Analog		verkauf@atp-messtechnik.de	+49 (0) 7822 8624	
Force gauge	Checkline (force gauge)	FGV-5XY	635,00	0,20	0,04	0,01	20	RS232C/USB/Analog	1	sales@checkline.eu	+31 (0)88 002900	Sanne de Goede
Force gauge	Checkline (force gauge)	FGV-100XY	635,00	0,20	1,00	0,1	500	RS232C/USB/Analog	1	sales@checkline.eu	+31 (0)88 002900	Sanne de Goede
Force gauge	Hahn+Kolb	44180-50	1800,00	0,05	0,25	0,01	500	USB		bestellung@hahn-kolb.de	0711 9813-366	
Load cell	ATP-Messtechnik	K-13 (compression without screw)	526,00	0,50	0,10	0,01	20			verkauf@atp-messtechnik.de	+49 (0) 7822 8624	
Load cell	ATP-Messtechnik	AK-1427(comp-tens)	758,00	0,10	0,50		500			verkauf@atp-messtechnik.de	+49 (0) 7822 8624	
Load cell	ATP-Messtechnik	K-11(comp-tens)	800,00	0,10	0,50	0,01	500			verkauf@atp-messtechnik.de	+49 (0) 7822 8624	
Load cell	ATP-Messtechnik	AK-2523 (comp)	350,00	1,00	2,00		200			verkauf@atp-messtechnik.de	+49 (0) 7822 8624	
Load cell	ATP-Messtechnik	USB-kit LCV-usb2-DMS	399,00							verkauf@atp-messtechnik.de	+49 (0) 7822 8624	
Load cell	Burster	8511-5010	355,00	0,50	0,05	0,001	10	9pin	1	HansJoachim.Legat@burster.de	+49-7224-645-5	Mr. Legat
Load cell	Burster	8523-20	435,00	0,50	0,10	0,001	20	9pin	1	HansJoachim.Legat@burster.de	+49-7224-645-5	Mr. Legat
Load cell	Burster	8511-5500	435,00	0,10	0,50	0,01	500	9pin	1	HansJoachim.Legat@burster.de	+49-7224-645-5	Mr. Legat
Load cell	Burster	8523-500	350,00	0,20	1,00	0,01	500	9pin	1	HansJoachim.Legat@burster.de	+49-7224-645-5	Mr. Legat
Load cell	Burster	USB-Kit	345,00					USB+LabView driver		HansJoachim.Legat@burster.de	+49-7224-645-5	Mr. Legat
Load cell	Lorenz-Messtechnik	K-13 (comp without screw)	510,00	0,50	0,10	0,01	20		3-4	h.welsing@lorenz-messtechnik.de	07172 / 93730-3	Hubert Welsing
Load cell	Lorenz-Messtechnik	K-11(comp-tens)	698,00	0,20	1,00	0,01	500		3-4	h.welsing@lorenz-messtechnik.de	07172 / 93730-3	Hubert Welsing
Load cell	Lorenz-Messtechnik	USB-kit LCV-usb2-DMS	276,00						3-4	h.welsing@lorenz-messtechnik.de	07172 / 93730-3	Hubert Welsing
Load cell	Prodynamics	iLoad Mini (10lb.) + DQ-1000A (comp	163+163	0,50	0,22		44	USB	6	info@prodynamics.com	+49 (0) 6970 79085	
Load cell	Prodynamics	iLoad Digital USB (50lb.) (comp)	217,00	0,15	0,33		222	USB	6	info@prodynamics.com	+49 (0) 6970 79085	
Load cell	Prodynamics	iLoad Pro Digital USB (250lb.) + TX-325 (comp-ten	435+140	0,15	1,67		1112	USB	6	info@prodynamics.com	+49 (0) 6970 79085	
Load cell	Prodynamics	iLoad Mini (200lb.) + DQ-1000A + TX-125 (comp-ten	163+163+70	0,50	4,45		890	USB	6	info@prodynamics.com	+49 (0) 6970 79085	
Load cell	Sensocon (Futek)	LLB130	404,24	0,50	0,11	0,010	22,2	USB	2-3	info@sensocon.de	+49-(0)6321-968401	Bernhard Unkel
Load cell	Sensocon (Futek)	LCB500	788,26	0,25	2,23	0,100	890	USB	2-3	info@sensocon.de	+49-(0)6321-968401	Bernhard Unkel
Load cell	Sensocon (Futek)	LCM300	363,81	0,50	5,56	0,100	1112	USB	2-3	info@sensocon.de	+49-(0)6321-968401	Bernhard Unkel
Load cell	Sensocon (Futek)	USB-Kit	404,24					LabView driver	2-3	info@sensocon.de	+49-(0)6321-968401	Bernhard Unkel
Load cell	Sensocon (Futek)	Calibration	242,54						2-3	info@sensocon.de	+49-(0)6321-968401	Bernhard Unkel

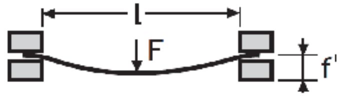
c. Displacement sensor selection

VARIANT	COMPANY	MODEL	PRICE [€]	ACCURACY ± [µm]	REPEATABILITY ± [µm]	RESOLUTION [mm]	MEASURING RANGE [mm]	NUMBER OF MEASUREMENTS [mes/s]	COMMUNICATION INTERFACE	DELIVERY TIME [weeks]	E-MAIL	TELEPHONE
Digital indicator	Studenroth (Sylvac)	2101-1050 (digital indicator)	755,00	20	20	0,0100	150	8	RS232,USB	3-3		
Digital indicator	Studenroth (Sylvac)	2101-1055 (digital indicator)	981,00	8	2	0,0010	150	5	RS232,USB	3-4		
Digital indicator	Studenroth (Sylvac)	2101-1045 (digital indicator)	599,00	8	2	0,0010	100	5	RS232,USB	3-4		
Digital indicator	Studenroth (Sylvac)	5001-2001 (cable RS232	70,50									
Digital indicator	Studenroth (Sylvac)	5001-3031 (cable USB	81,50									
Digital indicator	Hahn + Kolb	33172-030 (digital indicator)	740,00	8	2	0,0010	100	5	RS232		info@hahn-kolb.de	+49 (0) 711 98 13 - (
Digital indicator	Hahn + Kolb	33172-510 (RS232 cable	99,00									
Digital indicator	Mahr	4337023 (digital indicator)	745,00	8	2	0,0010	100	2-3	RS232,USB		handmesstechnik@mahr.de	+49 (0) 711 9312 - 60
Digital indicator	Mahr	4102410 (RS232 cable	49,75									
Digital indicator	Mahr	4102357 (USB cable	69,60									
Digital scale	Metav-Werkzeuge (Insize)	7102-150	64,00			0,0100	150		RS-232	2	l.bayer@metav-werkzeuge.d	+49 2822 914085
Digital scale	Mitutoyo	572-561		30		0,0100	150				info@mitutoyo.de or S.Heinen@mitutoyo.e	+49-(0) 2137-102-0 or 14
Digital scale	ASM	PCFP24		200		0,0100	150		analog+analog input card			
Digital scale	ASM	PCFP25		200	100	0,0100	150		analog+analog input card			
Digital scale	Studenroth (Sylvac)	4071-1502 (digital scale)	287,50	30	10	0,0100	150		RS232,USB	3-2	info@studenroth.com	+49 6187 90593-(
Linear scale	Metav-Werkzeuge (Insize)	ISL-AS-150	258,00	5,75		0,0050	150		RS-232	2		
Linear scale	Heidenhain (Walterbautz)	LC 483	775,00	5		0,0001	170		EnDat 2,2 incremental signa		twerner@walterbautz-gmbh.d	+49/6155-8422-3
Linear scale	Heidenhain (Walterbautz)	IK 220 (adapter PC card)	170,00						Drivers for visual c++, visual basic and borland delphi			
Linear scale	Heidenhain (Walterbautz)	Cable	64,00									
Linear scale	Mitutoyo	539-272		5,75			150					
Linear scale	Mitutoyo	539-254-10		3,51			170					
Linear scale	Numerik Jena	LIS 73-1		5		0,0010	170		RS421		info@numerikjena.de	+49 (0) 3641 4728 - 2
Linear scale	Numerik Jena	LIA21		5		0,0010	170		RS422			
Magnetic linear encoder	Renishaw	LM10IC010EA10A00 mag	623,00			0,0100	150		USB	8-11		
Magnetic linear encoder	ASM	PMIS3 (with mag band)		40	5	0,0100	150		Display unit + RS232		info@asm-sensor.de	+49-(0)8123-986-
Optical linear encoder	Renishaw	RGH41Y15D61A	983,00	3		0,0001	150		USB	8-10	Thomas.Renner@Renishaw.com	+49 7127 981-0 (direct-1417)

d. Profiles selection

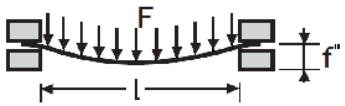
		Price (€/m)					Dead weight deflection	Case1 (unplug)		Case2 (plug)		Case1 (unplug)			
FIRMA	PROFILE	(bar of 6m)	I_x [cm⁴]	W_x [cm³]	Weight [kg/m]	Area [cm²]	f'' [mm]	f'_1 [mm]	f_1 [mm]	f'_2 [mm]	f_2 [mm]	M_b [Nmm]	σ [N/mm²]	$σ_{perm}$ [N/mm²]	State
Item	P8 40X40E	10,31	7,38	3,69	1,37	5,07	0,001	0,110	0,109	0,086	0,087	38416,50	10,41	130,00	OK
Item	P8 40X40 light	11,12	9,00	4,50	1,74	6,46	0,001	0,090	0,089	0,071	0,072	38583,00	8,57	130,00	OK
Item	P8 40X40	16,78	13,96	6,98	2,47	9,16	0,001	0,058	0,057	0,046	0,046	38911,50	5,57	130,00	OK
Item	P8 40X80 E	17,56	57,81	14,45	2,42	8,93	0,000	0,014	0,014	0,011	0,011	38889,00	2,69	130,00	OK
Item	P8 40X80 light	19,56	69,54	17,38	3,04	11,83	0,000	0,012	0,011	0,009	0,009	39168,00	2,25	130,00	OK
Item	P8 40X80	28,95	101,19	25,29	4,53	16,76	0,000	0,008	0,008	0,006	0,007	39838,50	1,58	130,00	OK
Item	P12 60X60 light	34,36	46,02	15,36	3,91	14,50	0,000	0,018	0,017	0,014	0,014	39559,50	2,58	130,00	OK
Item	P12 60X60	46,02	70,50	23,50	5,55	20,60	0,000	0,011	0,011	0,009	0,009	40297,50	1,71	130,00	OK
Minitec	45X45UL	12	9,953	4,423	1,445		0,001	0,081	0,081	0,064	0,065	38450,25	8,69	133,33	OK
Minitec	45X45F	12,80	14,17	6,30	2,01	7,426	0,001	0,057	0,056	0,045	0,046	38702,25	6,15	133,33	OK
Minitec	45X45	18,05	15,93	7,08	2,19		0,001	0,051	0,050	0,040	0,041	38786,40	5,48	133,33	OK
Minitec	45X60F	25,30	32,07	10,69	2,60	9,64	0,000	0,025	0,025	0,020	0,020	38971,35	3,65	133,33	OK
Minitec	60X60F	30,70	40,72	13,57	3,66		0,000	0,020	0,019	0,016	0,016	39444,75	2,91	133,33	OK
Minitec	45X90F	25,70	100,99	22,44	3,13	11,77	0,000	0,008	0,008	0,006	0,006	39210,30	1,75	133,33	OK
Paletti	Profil 40x40 superlight, natur	11,34	7,96	3,98	1,39	5,14	0,001	0,102	0,101	0,080	0,081	38426,85	9,65	130,00	OK
Paletti	Profil 40x40 semi, natur	12,79	9,17	4,59	1,75	6,44	0,001	0,088	0,087	0,069	0,070	38585,25	8,41	130,00	OK
Paletti	Profil 40x40 light, natur	14,01	7,82	3,91	1,54	5,67	0,001	0,104	0,103	0,081	0,082	38491,65	9,84	130,00	OK
Paletti	Profil 40x40 doppelsteg, natur	15,14	10,16	5,08	1,77	6,54	0,001	0,080	0,079	0,063	0,063	38597,40	7,60	130,00	OK
Paletti	Profil 40x40, natur	17,36	12,91	6,45	2,30	8,49	0,001	0,063	0,062	0,049	0,050	38835,00	6,02	130,00	OK
Paletti	Profil 40x80 superlight, natur	22,76	56,96	14,24	2,48	9,16	0,000	0,014	0,014	0,011	0,011	38916,90	2,73	130,00	OK
Paletti	Profil 40x80 semi, natur	23,29	69,49	17,37	3,03	11,18	0,000	0,012	0,011	0,009	0,009	39163,50	2,25	130,00	OK
Paletti	Profil 40x80 light, natur	25,51	60,79	15,20	2,65	9,80	0,000	0,013	0,013	0,010	0,011	38994,30	2,57	130,00	OK
Paletti	Profil 40x80 doppelsteg, natur	28,77	73,74	18,44	3,43	12,64	0,000	0,011	0,011	0,009	0,009	39341,25	2,13	130,00	OK
Paletti	Profil 40x80, natur	38,66	93,73	23,43	4,32	15,95	0,000	0,009	0,008	0,007	0,007	39744,90	1,70	130,00	OK

E [N/mm2]	70000	
G [N/mm2] (Minitec)	27000	
G [N/mm2] (Item)	25000	
L [mm]	600	
F1 [N]	504	=450+components' weight (54N)
F2 [N]	396	=450-components' weight (54N)
$R_{p0,2}$ (Minitec) [N/mm²]	200	
$R_{p0,2}$ (Item) [N/mm²]	195	
$R_{p0,2}$ (Paletti) [N/mm²]	195	
S	1,5	



$$f' = \frac{F \times l^3}{192 \times E \times I \times 10^4}$$

Deflection caused by the dead weight



$$f'' = \frac{F \times l^3}{384 \times E \times I \times 10^4}$$

Check of the bending stress

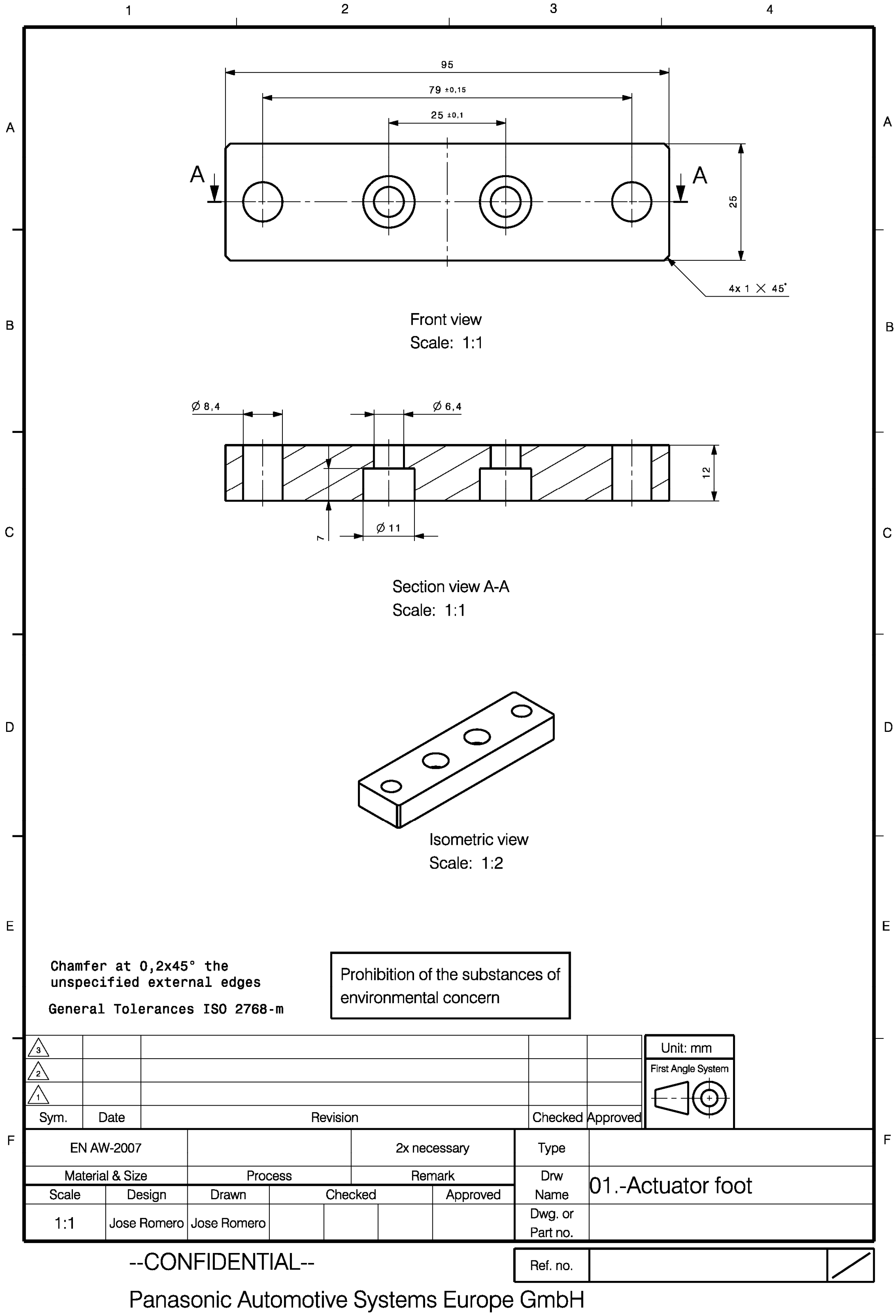
$$\sigma = \frac{M_b}{W \times 10^3}$$

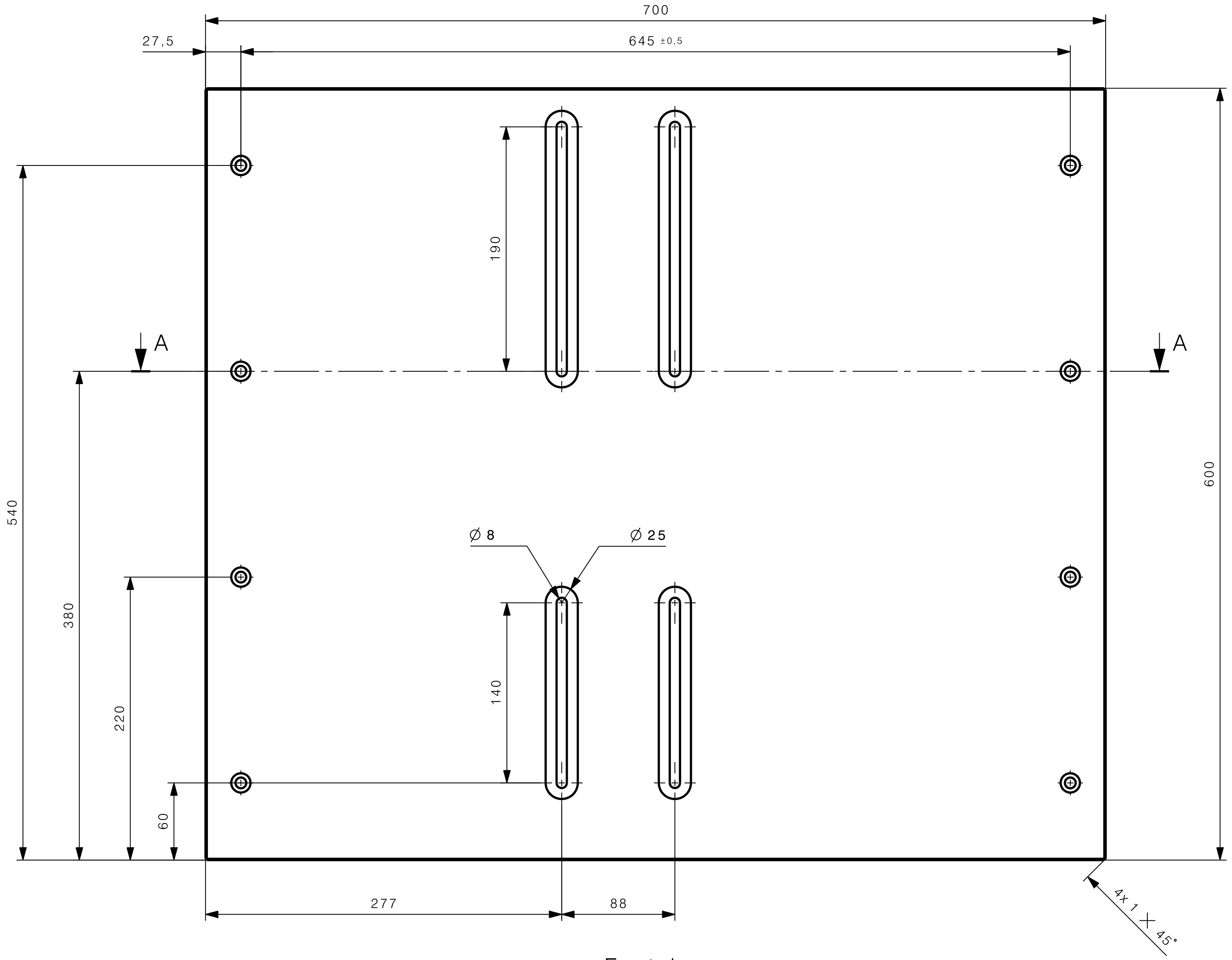
σ - Bending stress in N/mm²
M_b - Max. bending moment in Nmm
W - Resistance moment in cm³
$Rp_{0,2}$ = 195 N/mm²

The calculated bending stress σ must be compared with the permissible bending stress $σ_{perm}$.

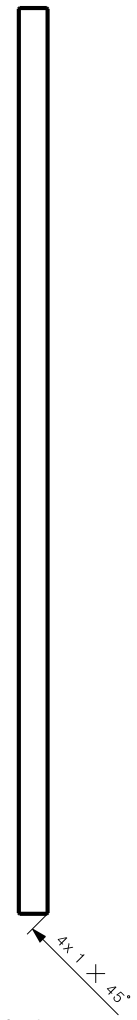
$$\sigma_{perm} = \frac{Rp_{0,2}}{S}$$

C. Drawings

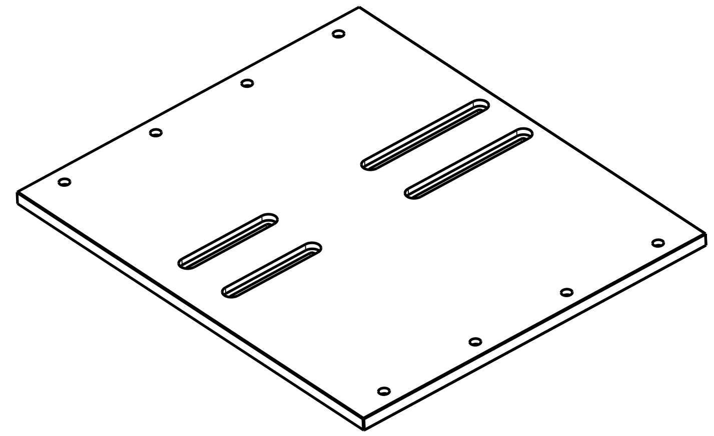

95
79 ±0,15
25 ±0,1
A
A
25
4x 1 X 45°
Front view
Scale: 1:1
Ø 8,4
Ø 6,4
12
Ø 11
7
Section view A-A
Scale: 1:1
Isometric view
Scale: 1:2
Chamfer at 0,2x45° the
unspecified external edges
General Tolerances ISO 2768-m
Prohibition of the substances of environmental concern
Sym.
Date
Revision
Checked
Approved
Unit: mm
First Angle System
EN AW-2007
2x necessary
Type
Material & Size
Process
Remark
Drw Name
01.-Actuator foot
Scale
Design
Drawn
Checked
Approved
Dwg. or Part no.
1:1
Jose Romero
Jose Romero
--CONFIDENTIAL--
Ref. no.
Panasonic Automotive Systems Europe GmbH



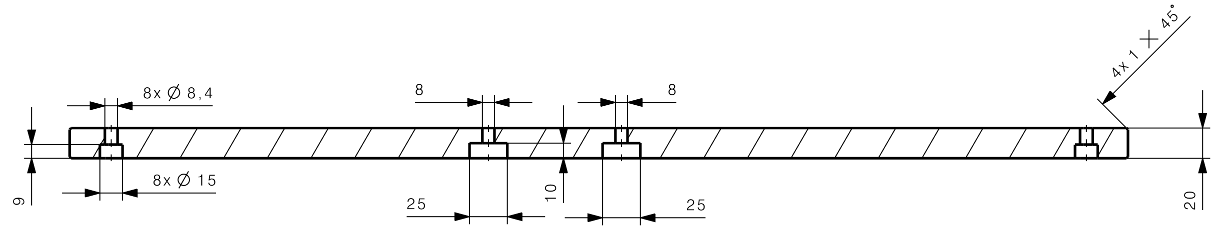
Front view
Scale: 1:5



Left view
Scale: 1:5



3D view
Scale: 1:10



Section view A-A
Scale: 1:5

Chamfer at 0,2x45° the unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm	EN AW-2007			Type	
First Angle System	Material & Size	Process	Remark	Drw. Name	02.-Table
	Scale	Design	Drawn	Checked	Approved
	1:5	Jose Romero	Jose Romero		
				Dwg. or Part no.	
				Ref. no.	

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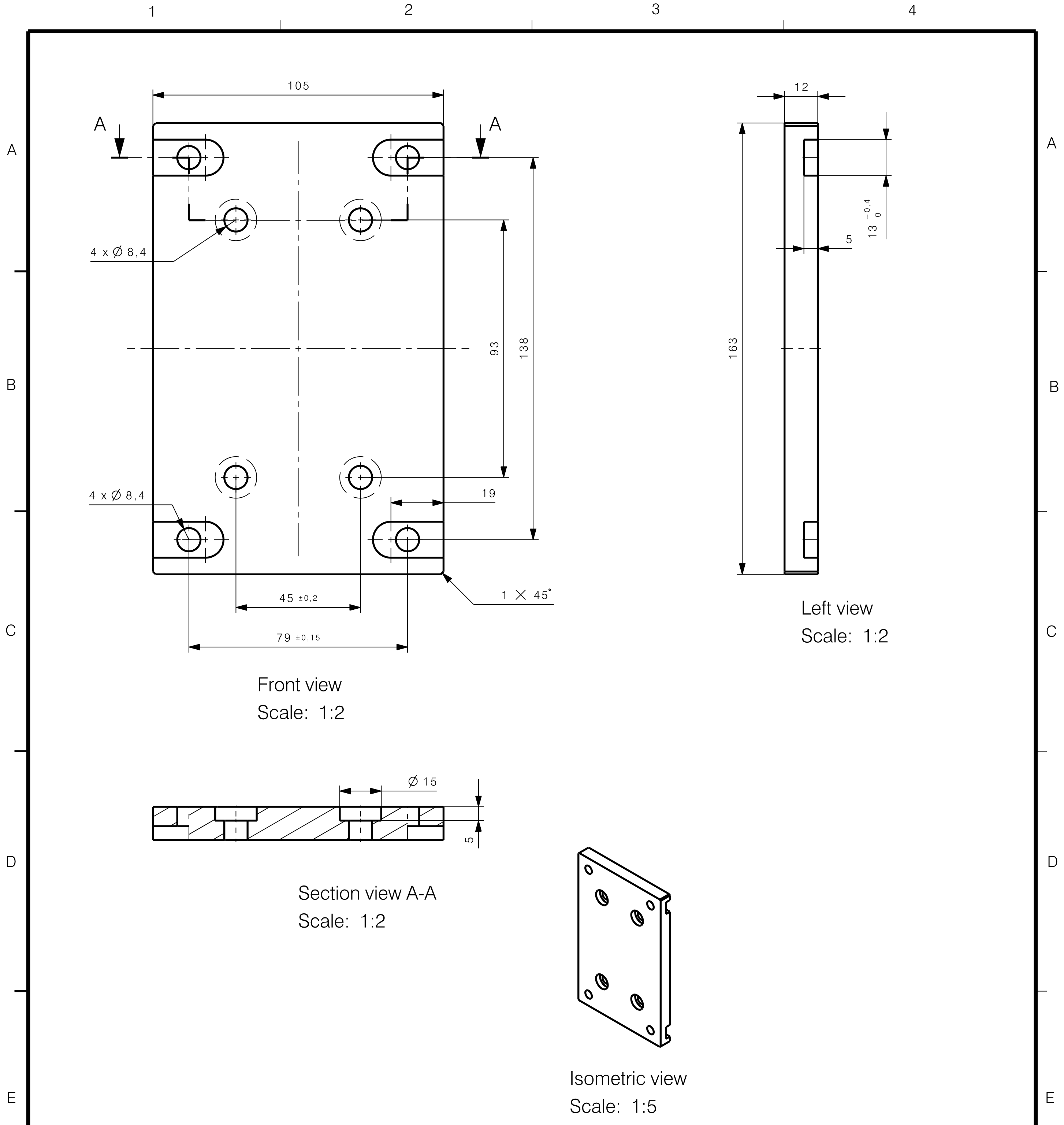

Front view
Scale: 1:2

Left view
Scale: 1:2

Section view A-A
Scale: 1:2

Isometric view
Scale: 1:5

Chamfer at 0,2x45° the unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm

First Angle System

Material & Size	Process	Remark	Type	
EN AW-2007			Drw Name	03.-Actuator fixation
			Dwg. or Part no.	

Scale	Design	Drawn	Checked	Approved
1:2	Jose Romero	Jose Romero		

Ref. no.

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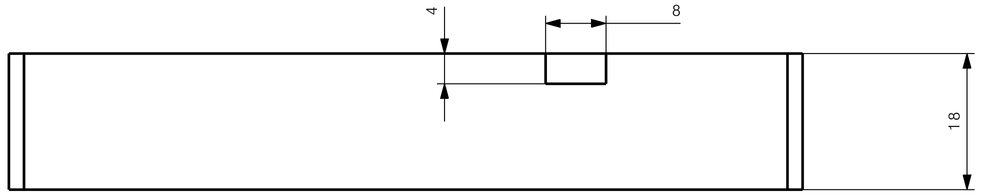
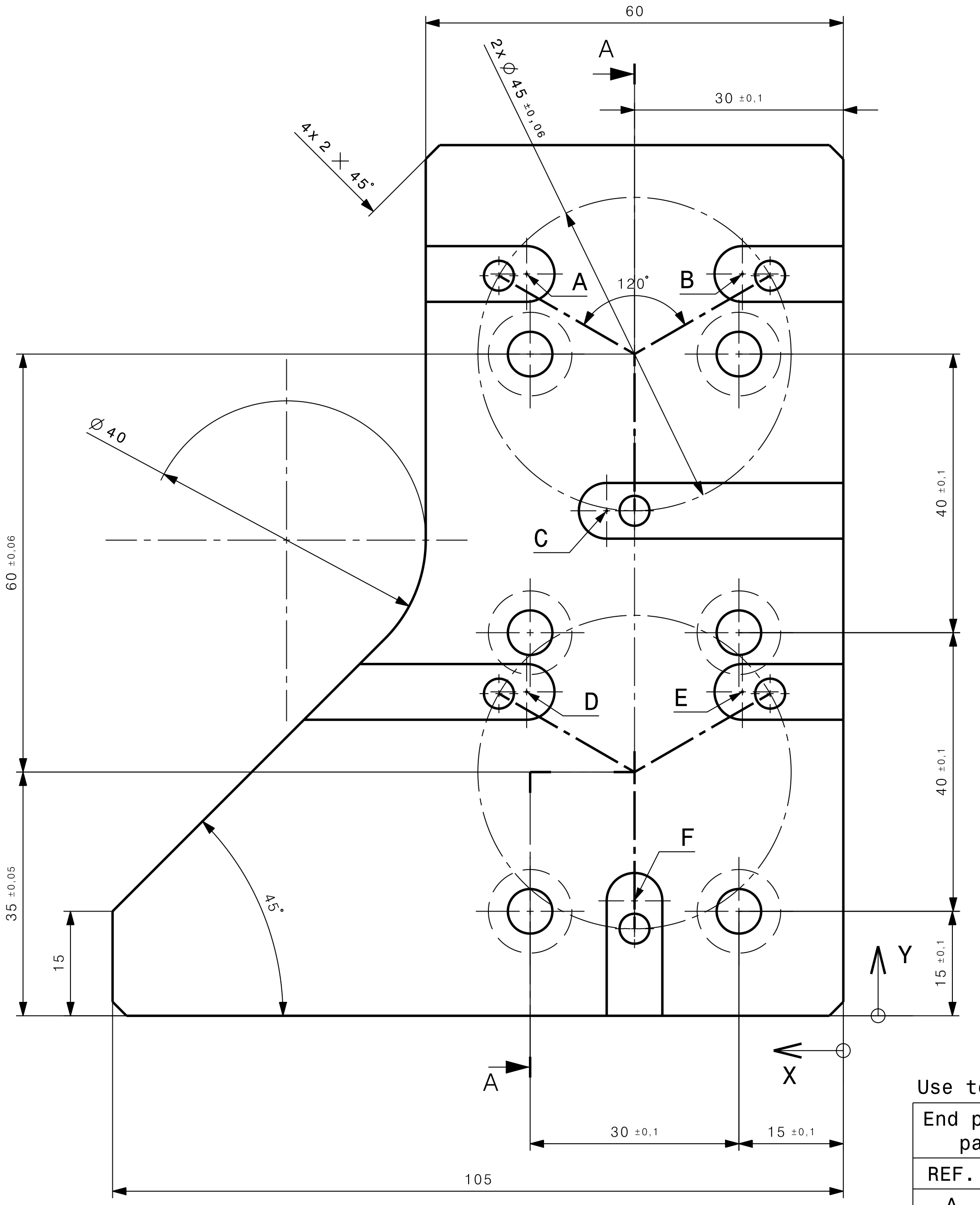
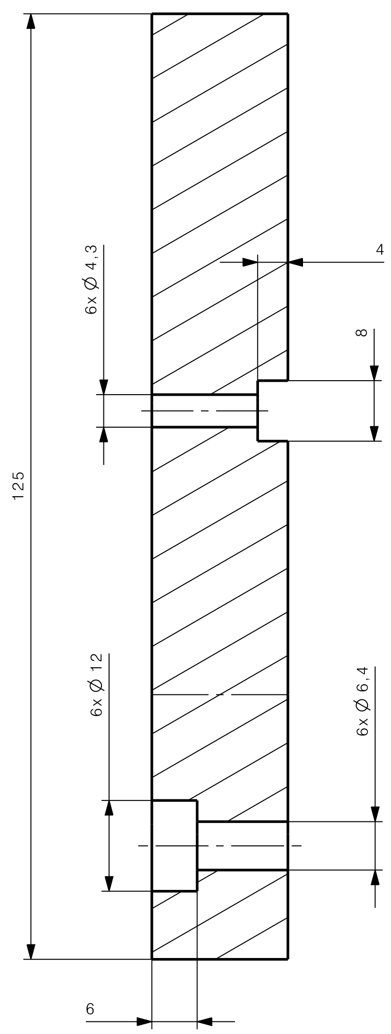


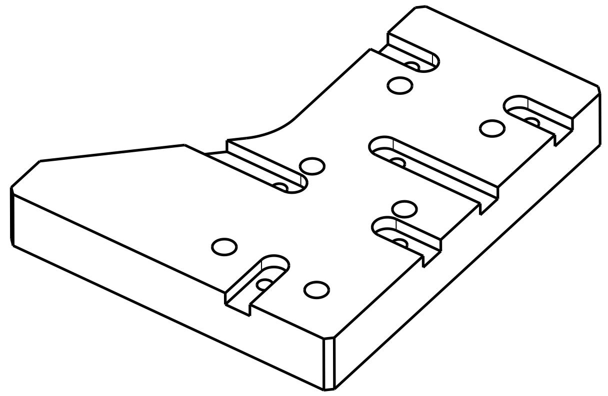
Bottom view
Scale: 1:1



Front view
Scale: 1:1



Section view A-A
Scale: 1:1



3D view
Scale: 1:2

Use tolerances ISO 2768-f

End point of slot drills parallel to X axis			
REF.	X	Y	R
A	45,5	106,5	8
B	14,5	106,5	8
C	34	72,5	8
D	45,5	46,5	8
E	14,5	46,5	8

End point of slot drills parrallel to Y axis			
REF.	X	Y	R
F	30	16,5	8

Chamfer at 0,2x45° the unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm	EN AW-2007				Type	
First Angle System	Material & Size	Process		Remark	Drw. Name	04.-Sensors fixation
	Scale	Design	Drawn	Checked	Approved	Dwg. or Part no.
	1:1	Jose Romero	Jose Romero			

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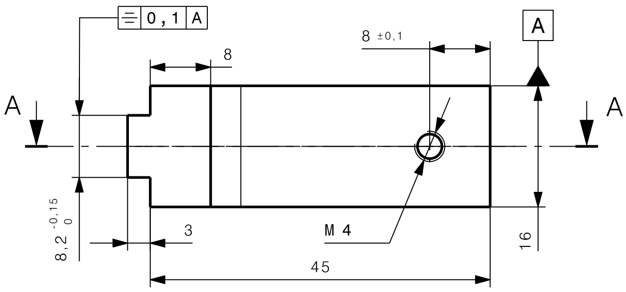
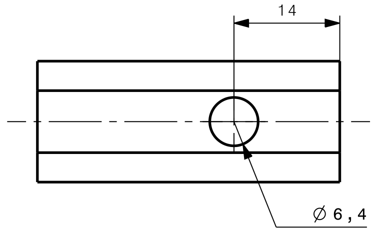
Ref. no.

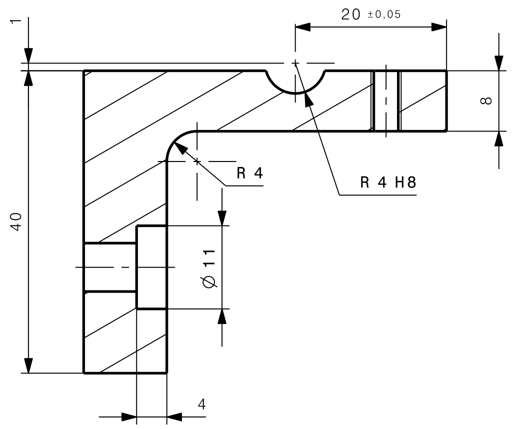
Panasonic Automotive Systems Europe GmbH



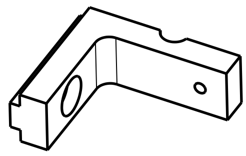
Front view
Scale: 1:1



Left view
Scale: 1:1



Section view A-A
Scale: 1:1



3D view
Scale: 1:2

Chamfer at 0,2x45° the unspecified external edges

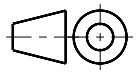
General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm

First Angle System



EN AW-2007			Type	
Material & Size	Process	Remark	Drw Name	05.-Digital indicator fixation L
Scale	Design	Drawn	Checked	Approved
1:1	Jose Romero	Jose Romero		
			Dwg. or Part no.	
			Ref. no.	

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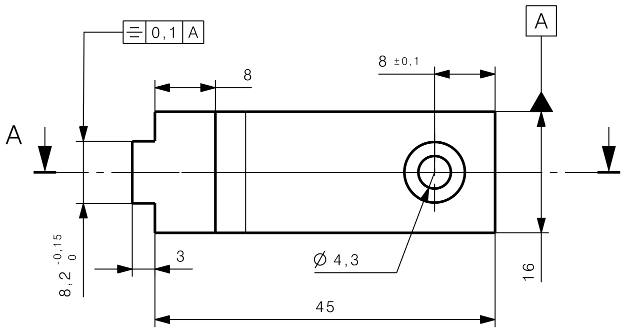
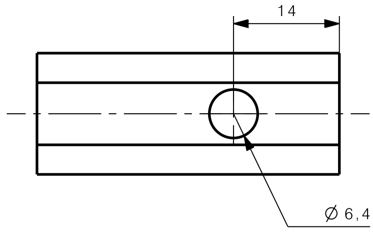
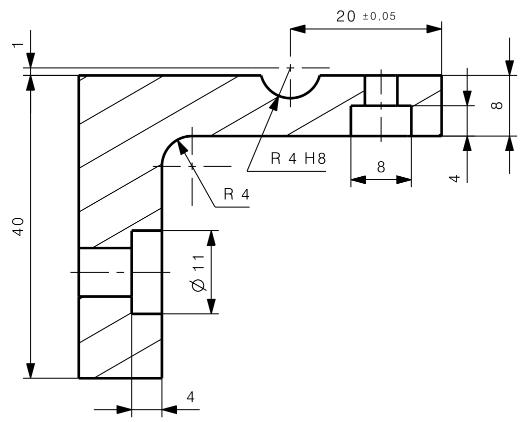
Panasonic Automotive Systems Europe GmbH



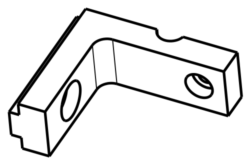
Front view
Scale: 1:1



Left view
Scale: 1:1



Section view A-A
Scale: 1:1



3D view
Scale: 1:2

```
Chamfer at 0,2x45° the
unspecified external edges

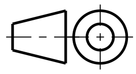
General Tolerances ISO 2768-m
```

Prohibition of the substances of environmental concern

3				
2				
1				
Sym.	Date	Revision	Checked	Approved

Unit: mm

First Angle System



EN AW-2007				Type	
Material & Size		Process	Remark	Drw Name	06.-Digital indicator fixation R
Scale	Design	Drawn	Checked	Approved	
1:1	Jose Romero	Jose Romero			Dwg. or Part no.	

Ref. no.	

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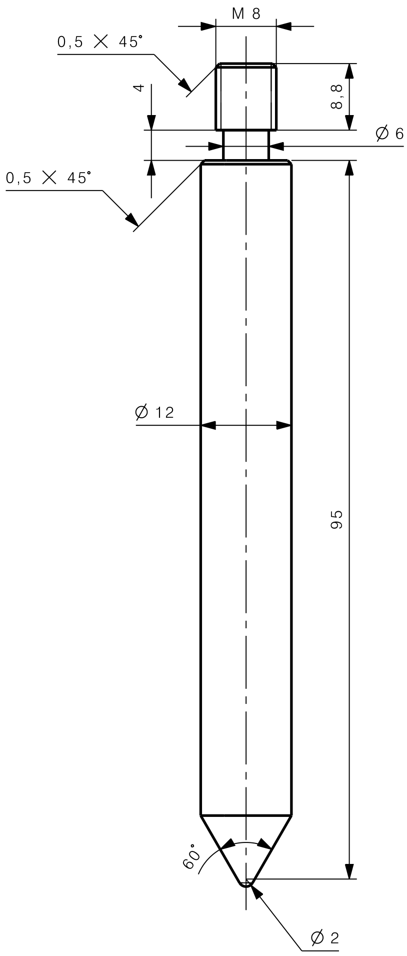
Panasonic Automotive Systems Europe GmbH



Front view
Scale: 1:1

Isometric view
Scale: 1:2

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm
First Angle System

Material & Size	Process	Remark
S235JR		

Scale	Design	Drawn	Checked	Approved
1:1	Jose Romero	Jose Romero		

Type	
Drw Name	07.-Load cell end. Button test.
Dwg. or Part no.	
Ref. no.	

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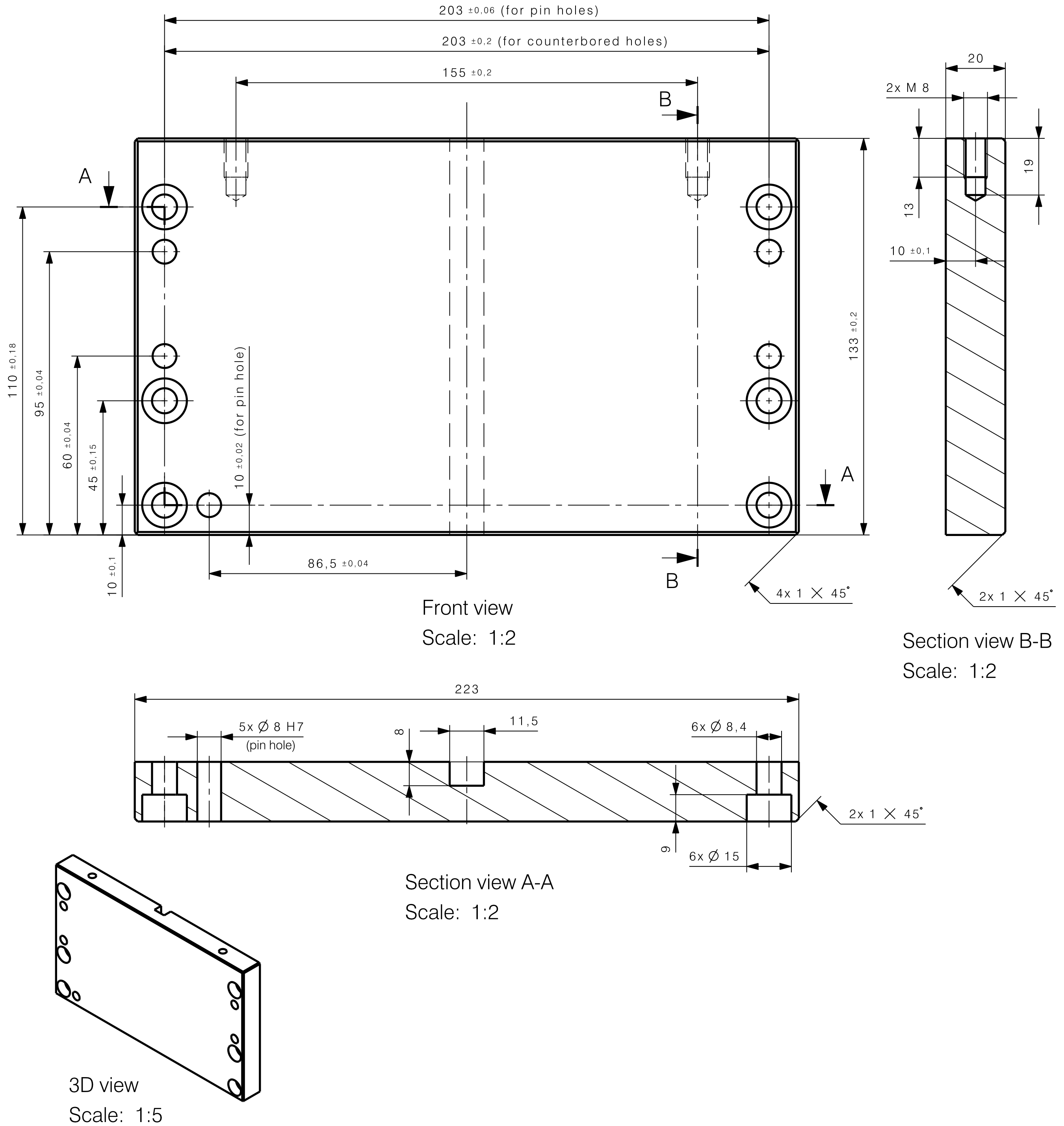
Panasonic Automotive Systems Europe GmbH



Chamfer at 0,2x45° the unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm

First Angle System

Material & Size	Process	Remark		
EN AW-2007			Type	
			Drw Name	08.-Radio fixation 1
			Dwg. or Part no.	

Scale	Design	Drawn	Checked			Approved
1:2	Jose Romero	Jose Romero				

Ref. no.		

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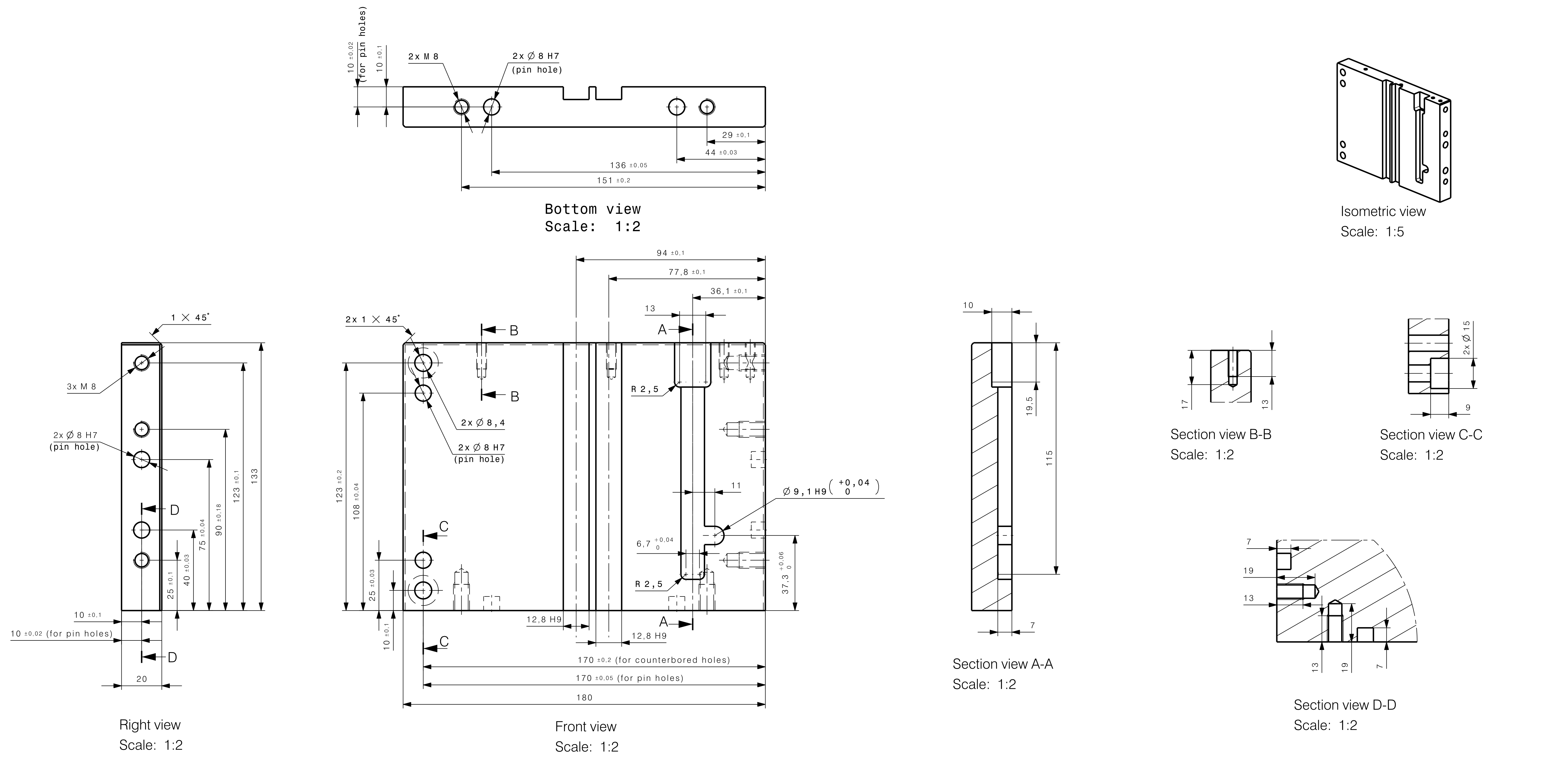
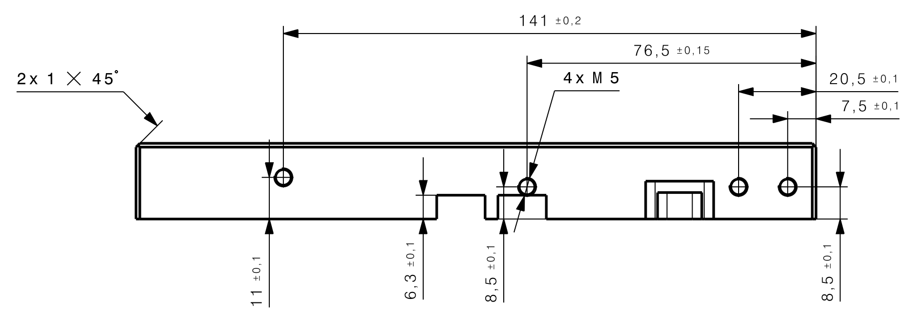
Panasonic Automotive Systems Europe GmbH





Top view
Scale: 1:2

Chamfer at 0,2x45° the unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm	EN AW-2007				Type	
First Angle System	Material & Size	Process		Remark	Drw. Name	09.-Radio fixation 2
	Scale	Design	Drawn	Checked	Approved	
	1:2	Jose Romero	Jose Romero			Dwg. or Part no.
					Ref. no.	

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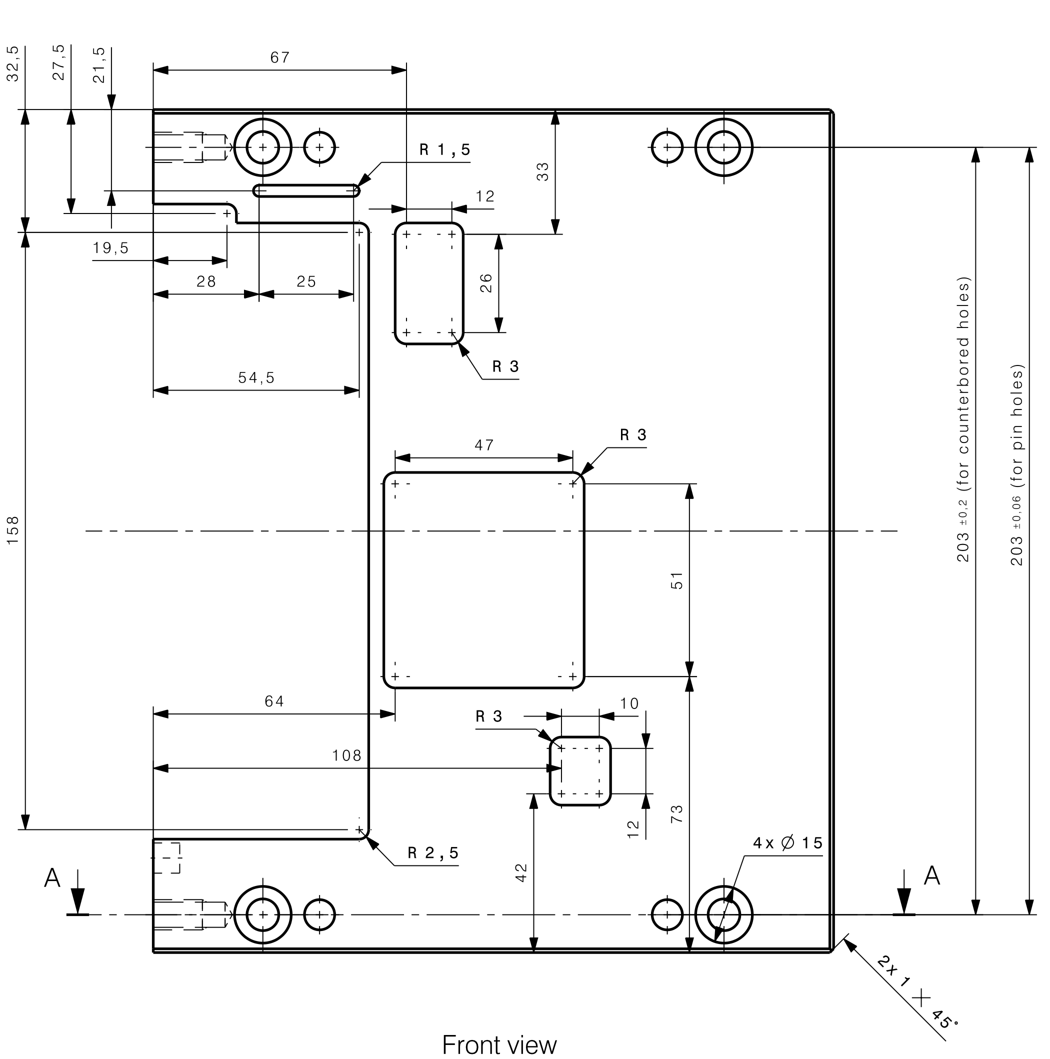
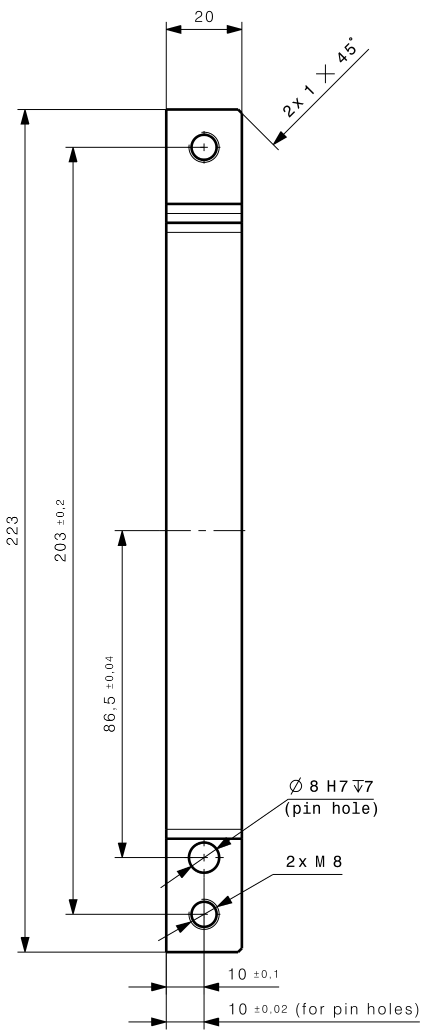
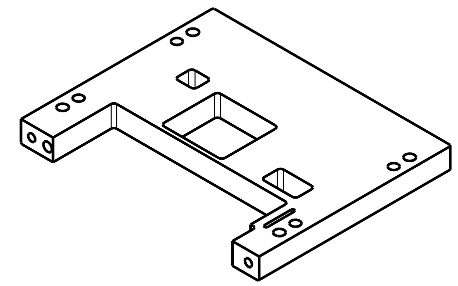


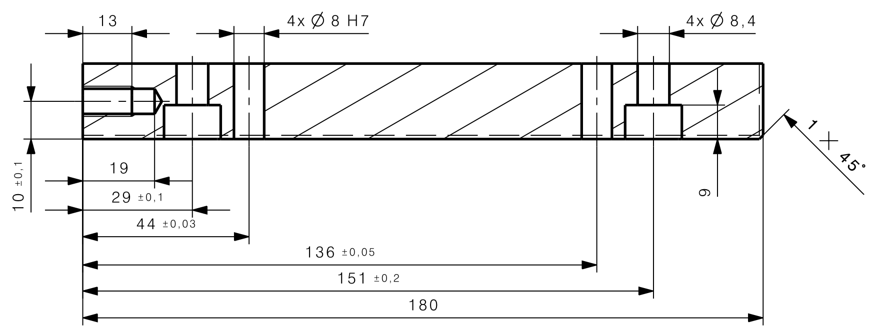
Front view
Scale: 1:2



Left view
Scale: 1:2



3D view
Scale: 1:5



Section view A-A
Scale: 1:2

Chamfer at 0,2x45° the
unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm	EN AW-2007			
First Angle System	Material & Size	Process	Remark	
	Scale	Design	Drawn	Checked	Approved
	1:2	Jose Romero	Jose Romero		

Type	
Drw. Name	10.-Radio fixation 3
Dwg. or Part no.	
Ref. no.	

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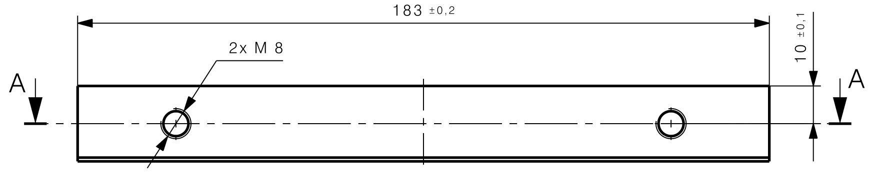
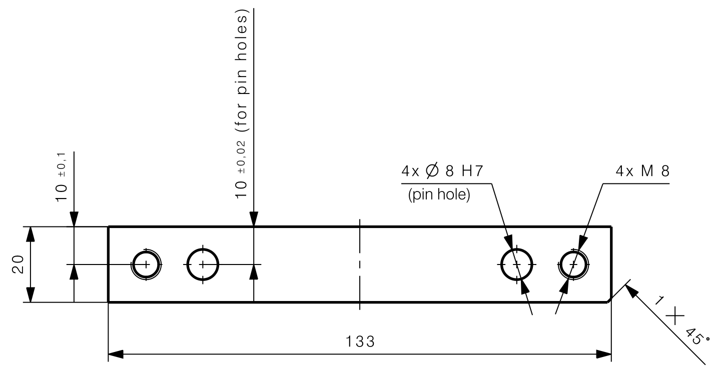
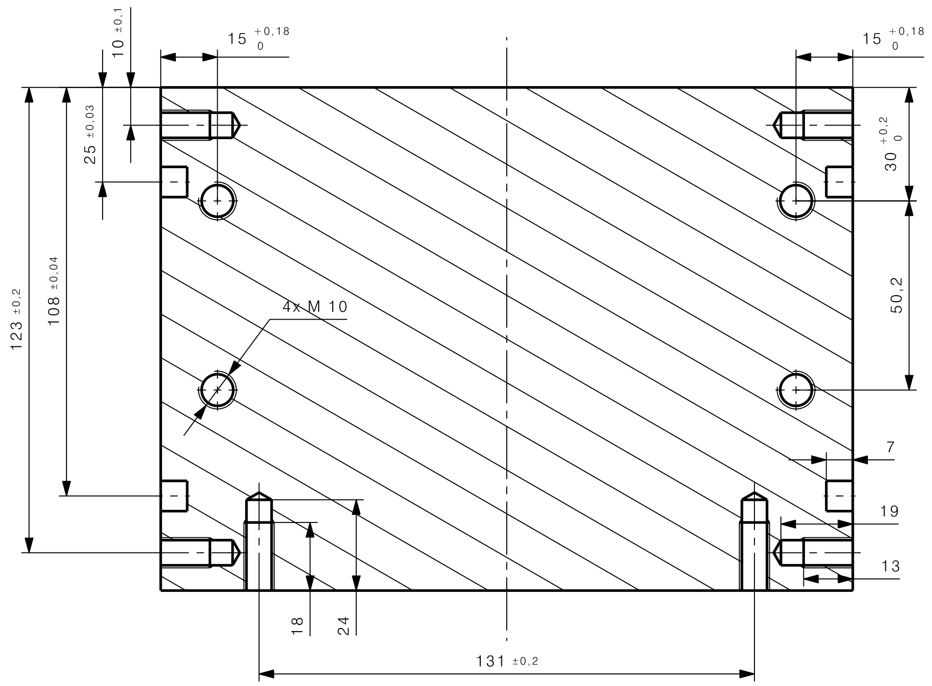


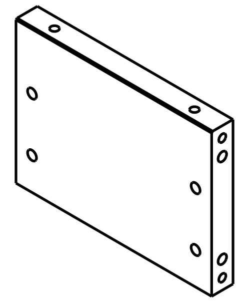
Front view
Scale: 1:2



Left view
Scale: 1:2



Section view A-A
Scale: 1:2



3D view
Scale: 1:5

Chamfer at 0,2x45° the
unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm	EN AW-2007				Type	
First Angle System	Material & Size	Process		Remark	Drw. Name	11.-Radio Fixation 4
	Scale	Design	Drawn	Checked	Approved	
	1:2	Jose Romero	Jose Romero			Dwg. or Part no.
					Ref. no.	

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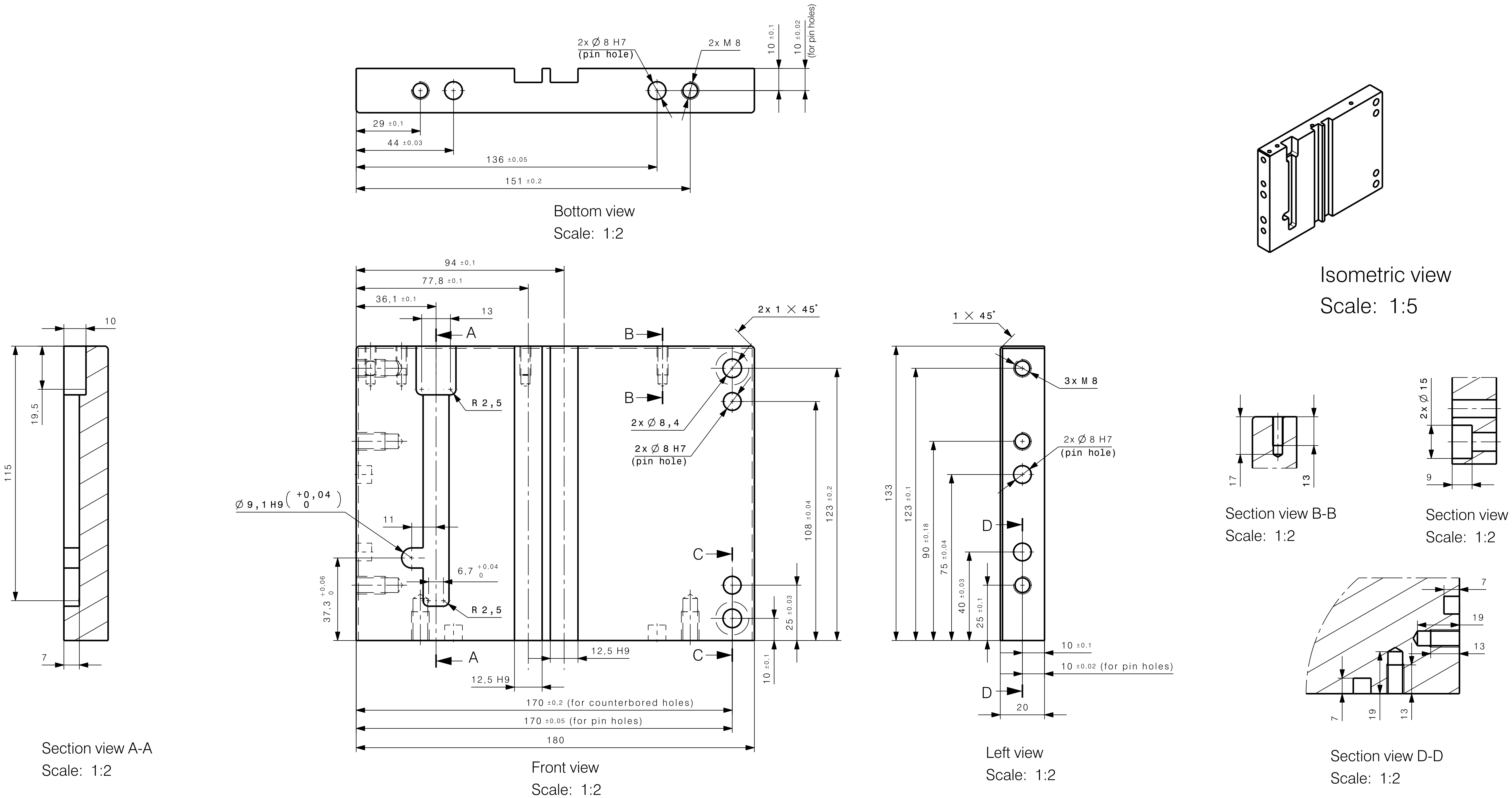
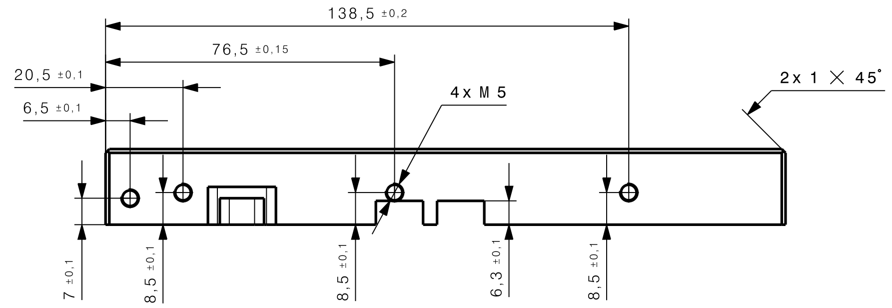
Panasonic Automotive Systems Europe GmbH





Top view
Scale: 1:2

Chamfer at 0,2x45° the unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm	EN AW-2007				Type	
First Angle System	Material & Size	Process		Remark	Drw. Name	12.-Radio fixation 5
	Scale	Design	Drawn	Checked	Approved	
	1:2	Jose Romero	Jose Romero			Dwg. or Part no.
					Ref. no.	

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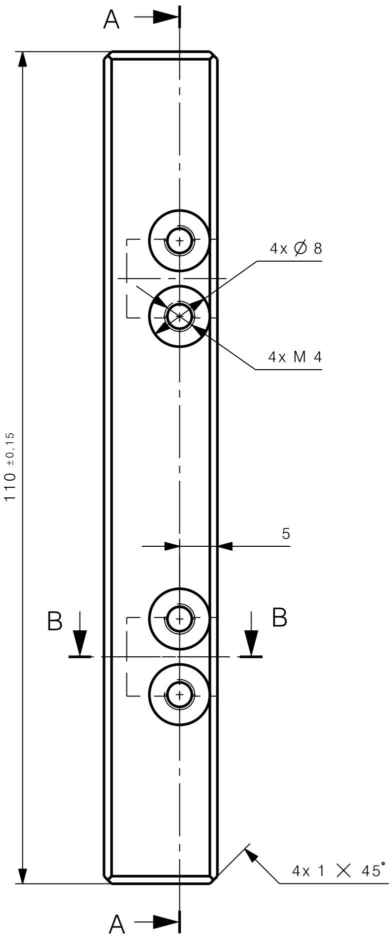
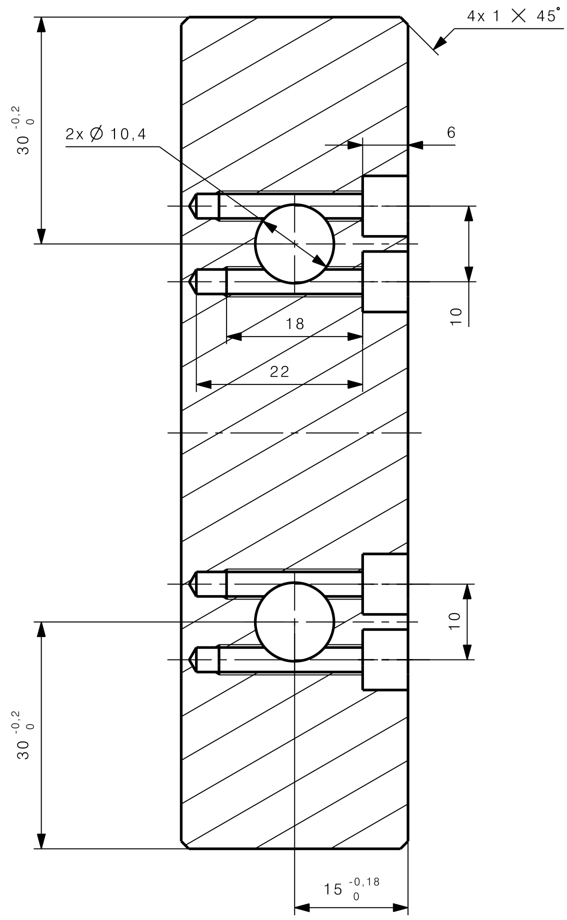
Panasonic Automotive Systems Europe GmbH



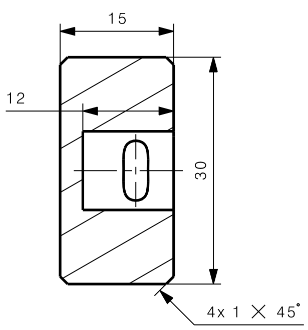
Front view

Scale: 1:1



Section view A-A

Scale: 1:1



Section view B-B

Scale: 1:1

Isometric view

Scale: 1:5

Chamfer at 0,2x45° the
unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm

First Angle System

EN AW-2007		2x necessary	Type	
Material & Size	Process	Remark	Drw Name	13.-Radio fixation 6
Scale	Design	Drawn	Checked	Approved
1:1	Jose Romero	Jose Romero		
			Dwg. or Part no.	
			Ref. no.	

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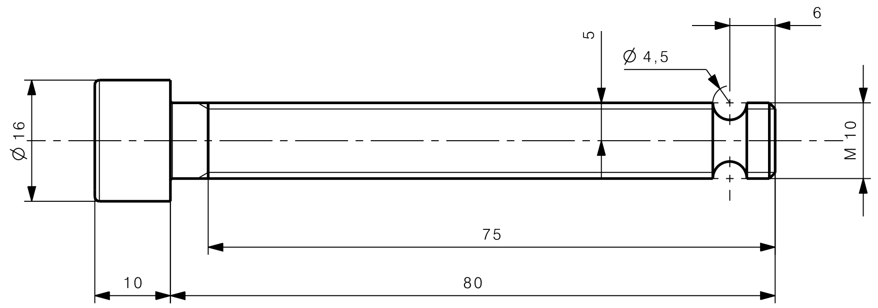
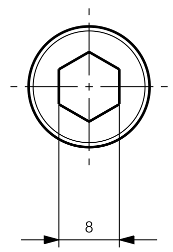
Panasonic Automotive Systems Europe GmbH



Front view
Scale: 1:1



Left view
Scale: 1:1

Prohibition of the substances of environmental concern

General Tolerances ISO 2768-m

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm
First Angle System

Material & Size	Process	Remark		
8.8		4x necessary	Type	
			Drw Name	14.-Screw guide M10x80
			Dwg. or Part no.	

Scale	Design	Drawn	Checked	Approved
1:1	Jose Romero	Jose Romero		

Ref. no.	

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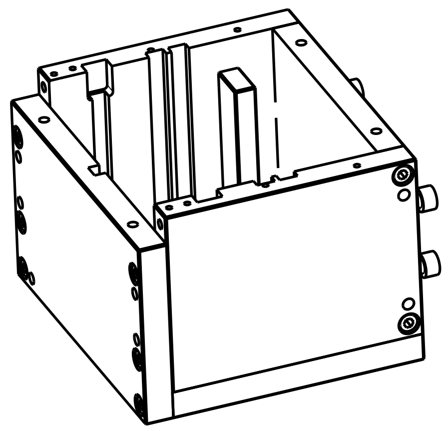
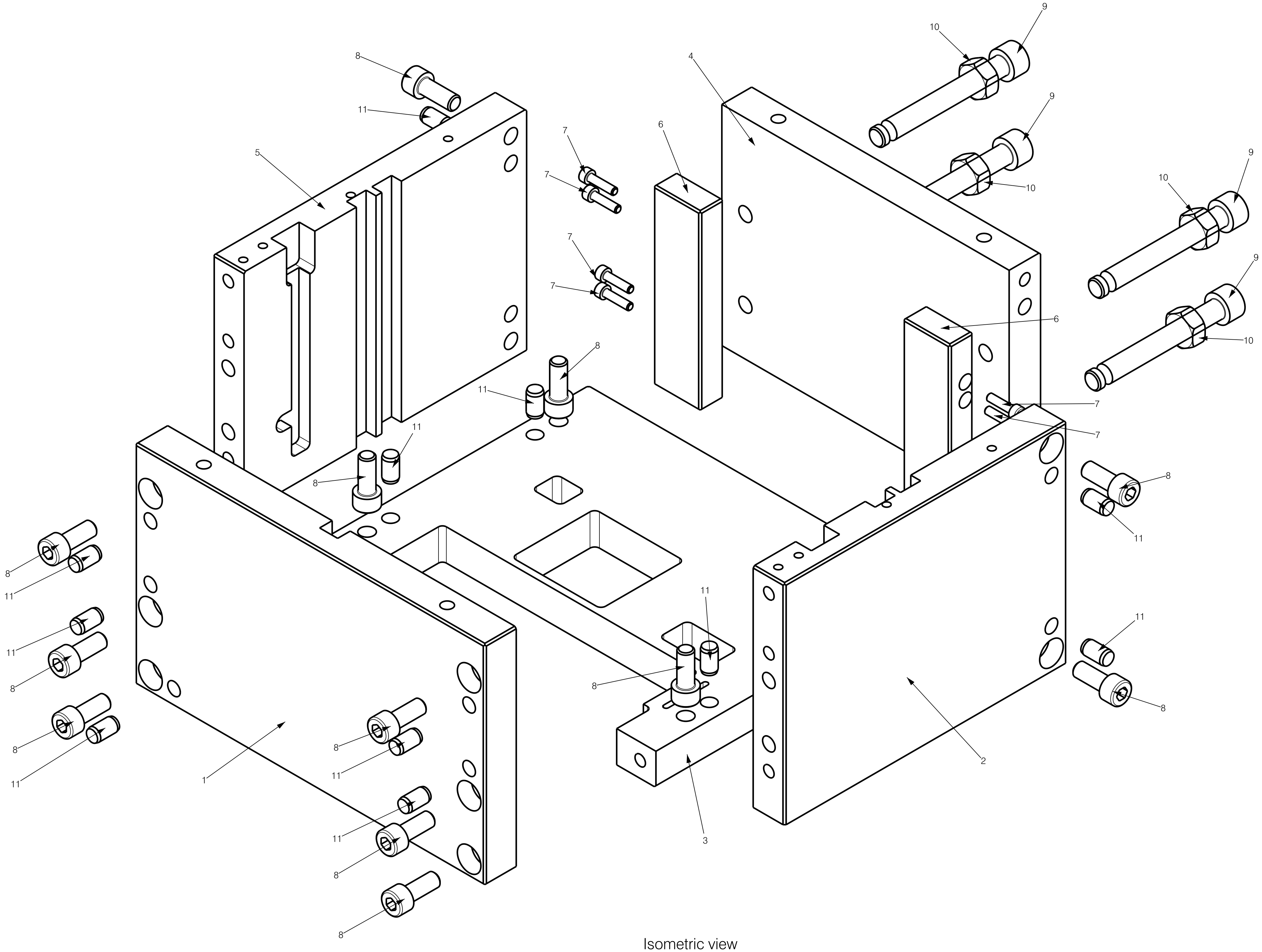
Panasonic Automotive Systems Europe GmbH



3D view
Scale: 1:5



Isometric view
Scale: 1:2

ITEM	QTY	PART NUMBER	MATERIAL
11	13	DIN 7 Φ8h8 x 14	St
10	4	DIN 555 M10	8.8
9	4	Screw guide M10x80	8.8
8	14	DIN 912 M8x20	8.8
7	8	DIN 912 M4x16	8.8
6	2	Radio fixation 6	EN AW-2007
5	1	Radio fixation 5	EN AW-2007
4	1	Radio fixation 4	EN AW-2007
3	1	Radio fixation 3	EN AW-2007
2	1	Radio fixation 2	EN AW-2007
1	1	Radio fixation 1	EN AW-2007

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Prohibition of the substances of environmental concern

Unit: mm				Type	
First Angle System	Material & Size	Process	Remark	Drw. Name	15.-Radio fixation assembly
	Scale	Design	Drawn	Checked	Approved
	1:2	Jose Romero	Jose Romero		Dwg. or Part no.

Ref. no.

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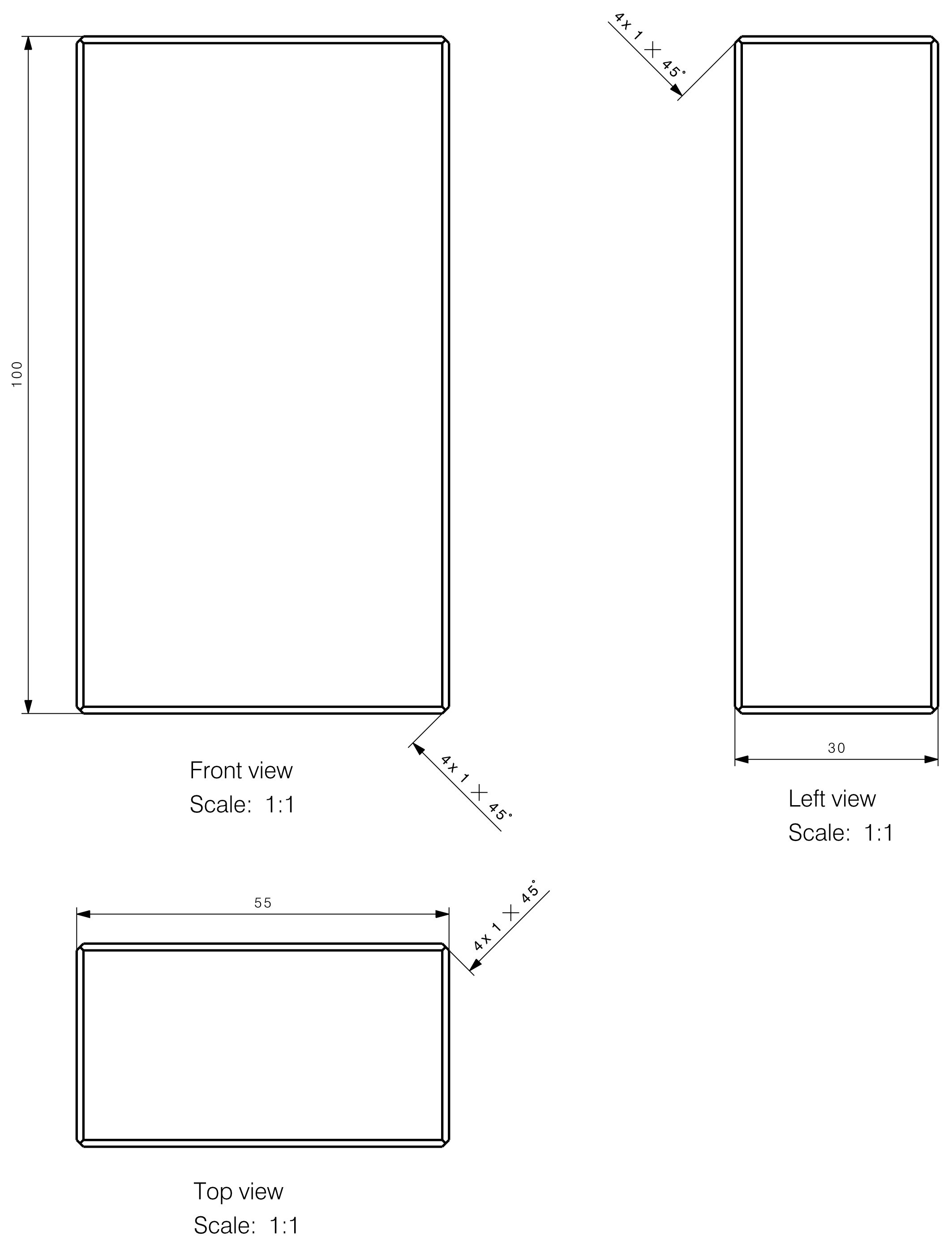
Panasonic Automotive Systems Europe GmbH



Prohibition of the substances of environmental concern

General Tolerances ISO 2768-m

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm

First Angle System

Material & Size	Process	Remark		
EN AW-2007		2x necessary	Type	
			Drw Name	16.-MIB spacer
			Dwg. or Part no.	

Scale	Design	Drawn	Checked			Approved
1:1	Jose Romero	Jose Romero				

Ref. no.		

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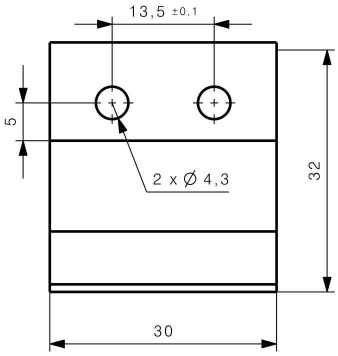
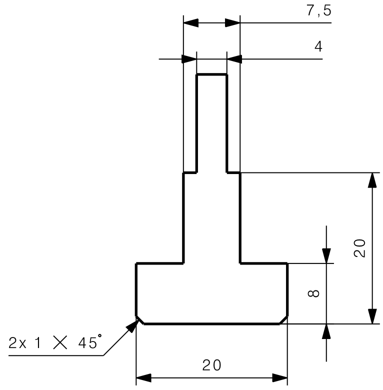
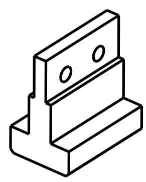
Panasonic Automotive Systems Europe GmbH



Front view
Scale: 1:1



Left view
Scale: 1:1



3D view
Scale: 1:2

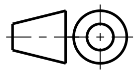
Chamfer at 0,2x45° the
unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm
First Angle System



Material & Size	Process	Remark	Type	
S235JR		4x necessary		
			Drw Name	17.-Clamp fixation

Scale	Design	Drawn	Checked			Approved	Dwg. or Part no.	
1:1	Jose Romero	Jose Romero						

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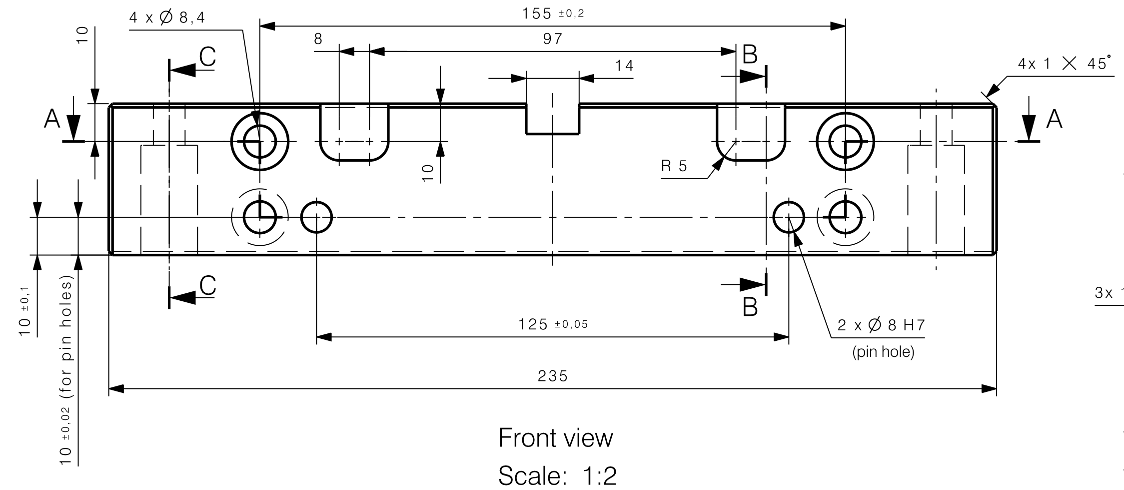
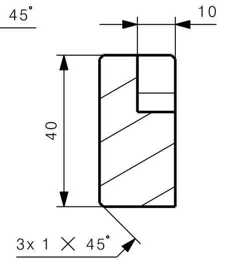
Ref. no.	

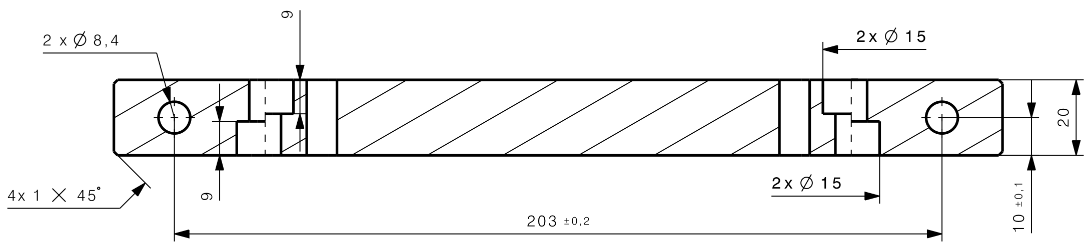
Panasonic Automotive Systems Europe GmbH



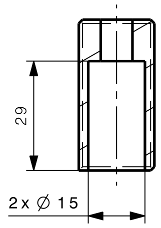
Front view
Scale: 1:2



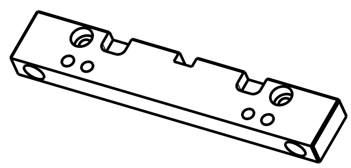
Section view B-B
Scale: 1:2



Section view A-A
Scale: 1:2



Section view C-C
Scale: 1:2



3D view
Scale: 1:5

Chamfer at 0,2x45° the unspecified external edges

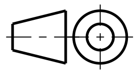
General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

3				
2				
1				
Sym.	Date	Revision	Checked	Approved

Unit: mm

First Angle System



EN AW-2007			Type	
Material & Size	Process	Remark	Drw Name	18.-Foot 1

Scale	Design	Drawn	Checked		Approved	
1:2	Jose Romero	Jose Romero				Dwg. or Part no.

Ref. no.	

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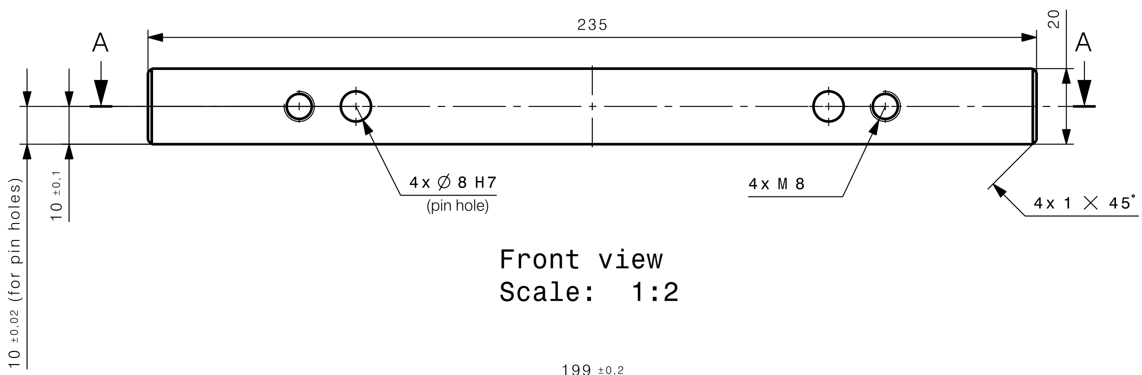
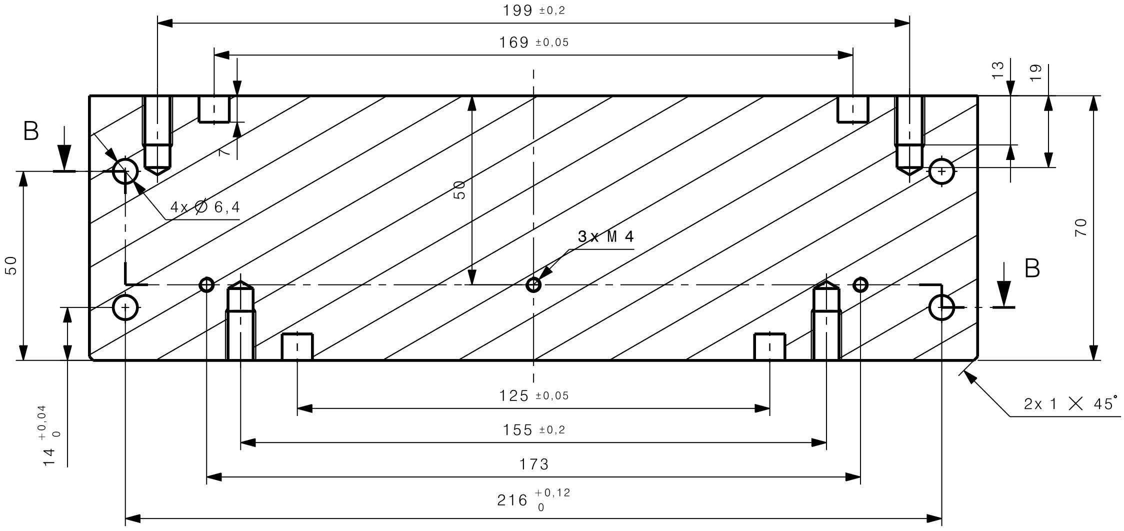
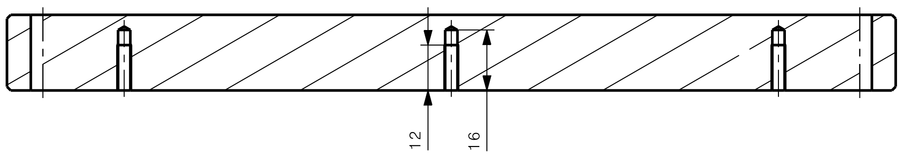
Panasonic Automotive Systems Europe GmbH



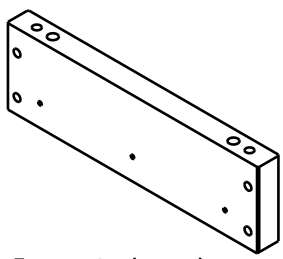
Front view
Scale: 1:2



Section view A-A
Scale: 1:2



Section view B-B
Scale: 1:2



Isometric view
Scale: 1:5

Chamfer at 0,2x45° the unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm

First Angle System

Material & Size	Process	Remark		
EN AW-2007			Type	
Scale	Design	Drawn	Checked	Approved
1:2	Jose Romero	Jose Romero		

Drw Name	19.-Foot 2
Dwg. or Part no.	
Ref. no.	

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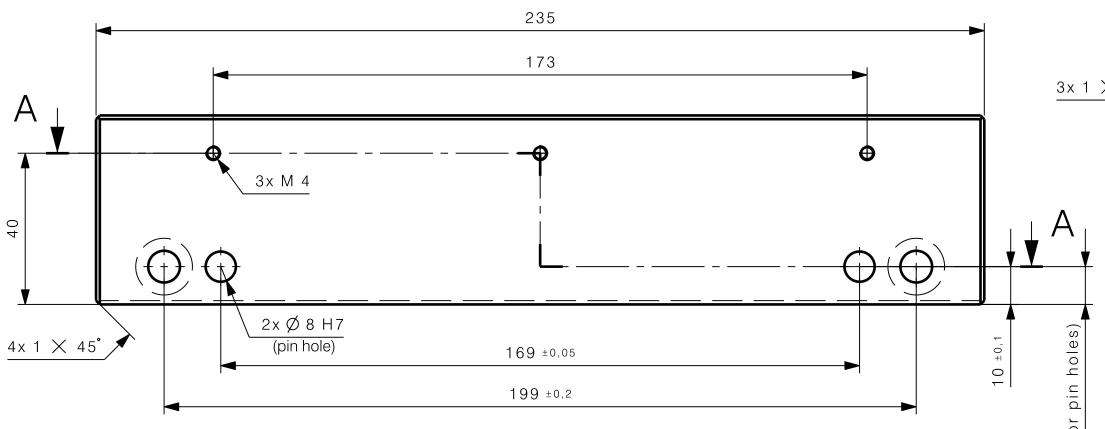
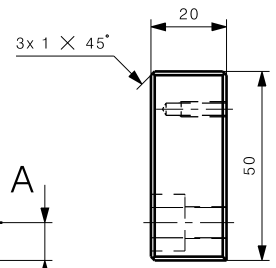
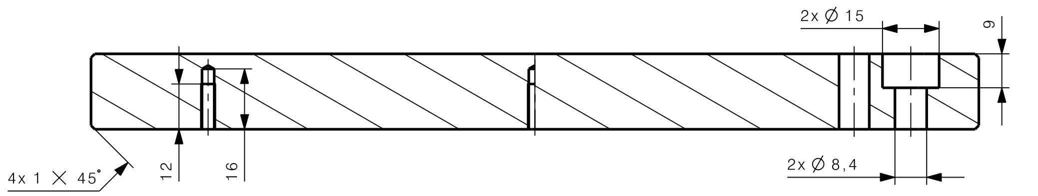
1 2 3 4



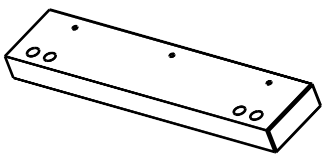
Front view
Scale: 1:2



Left view
Scale: 1:2



Section view A-A
Scale: 1:2



3D view
Scale: 1:5

Chamfer at 0,2x45° the unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm
First Angle System

Material & Size	Process	Remark		
EN AW-2007			Type	
Scale	Design	Drawn	Checked	Approved
1:2	Jose Romero	Jose Romero		
			Drw Name	20.-Foot 3
			Dwg. or Part no.	
			Ref. no.	

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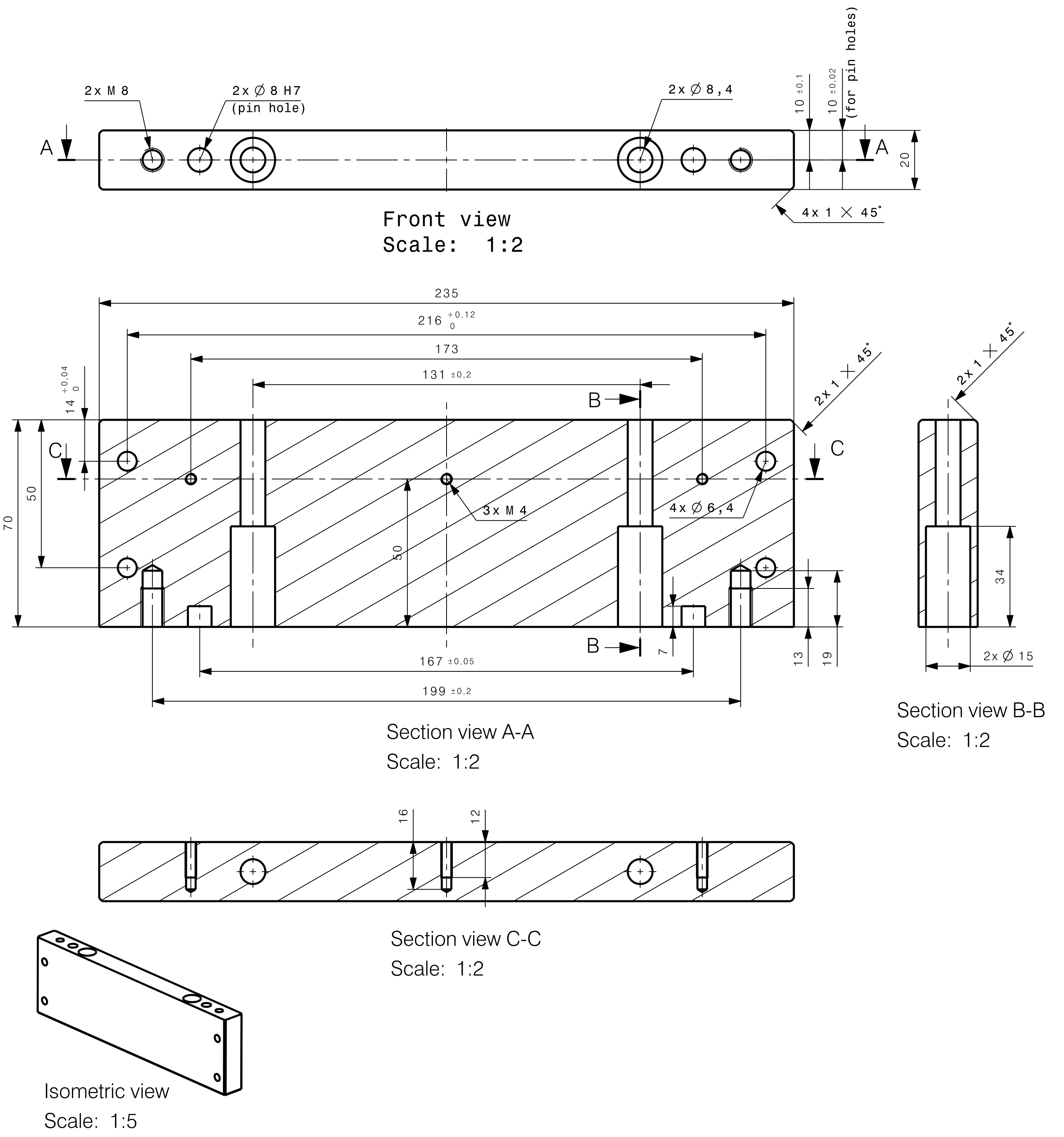

Chamfer at 0,2x45° the unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm

First Angle System

EN AW-2007			Type
Material & Size	Process	Remark	Drw Name: 21.-Foot 4
Scale: 1:2	Design: Jose Romero	Drawn: Jose Romero	Checked / Approved
			Dwg. or Part no.
			Ref. no.

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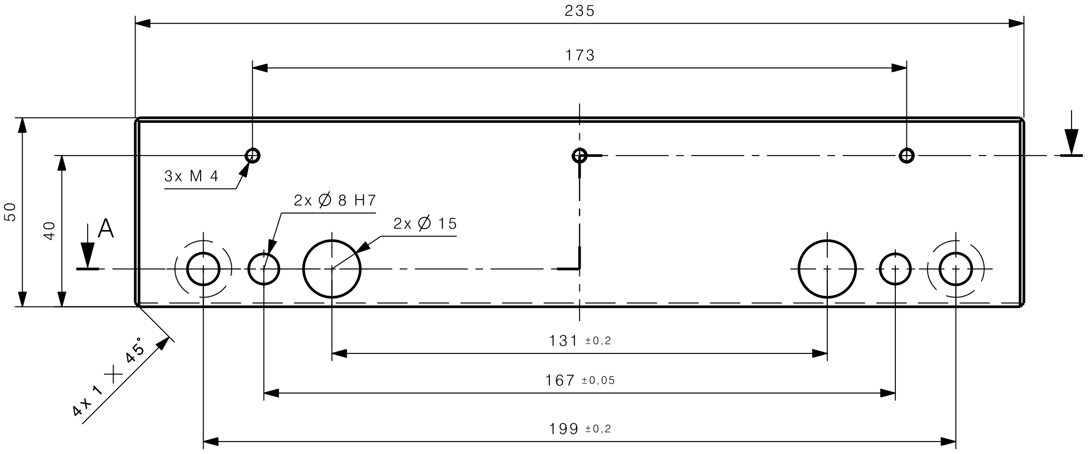
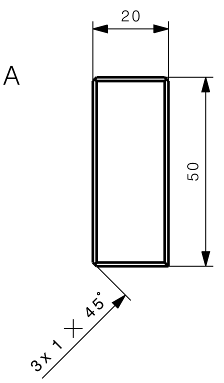
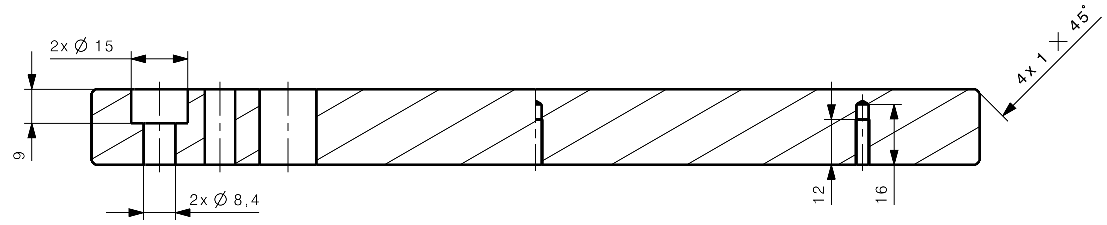


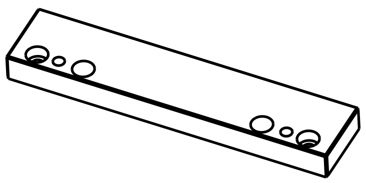
Front view
Scale: 1:2



Left view
Scale: 1:2



Section view A-A
Scale: 1:2



3D view
Scale: 1:5

Chamfer at 0,2x45° the unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm
First Angle System

Material & Size	Process	Remark		
EN AW-2007			Type	
Scale	Design	Drawn	Checked	Approved
1:2	Jose Romero	Jose Romero		
			Drw Name	22.-Foot 5
			Dwg. or Part no.	

Ref. no.		

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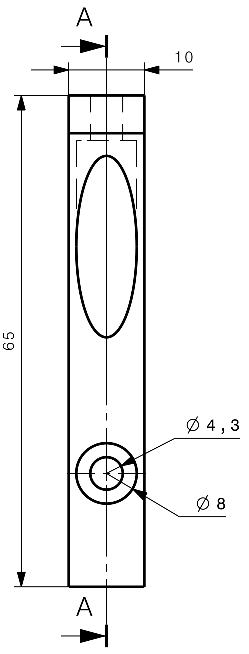
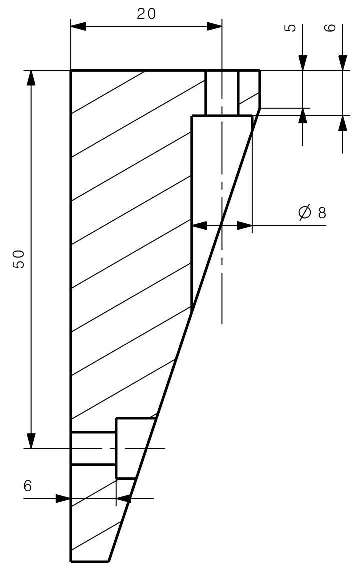
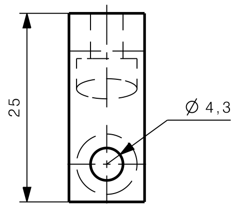
Panasonic Automotive Systems Europe GmbH



Front view
Scale: 1:1



Section view A-A
Scale: 1:1



Top view
Scale: 1:1

Chamfer at 0,2x45° the unspecified external edges

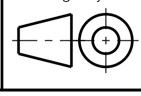
General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm

First Angle System



EN AW-2007		6x necessary	Type
Material & Size	Process	Remark	Drw Name: 23.-Foot 6

Scale	Design	Drawn	Checked	Approved	
1:1	Jose Romero	Jose Romero			Dwg. or Part no.

Ref. no.		

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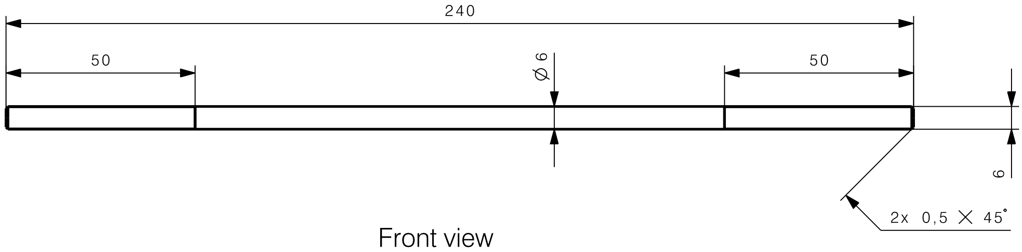
Panasonic Automotive Systems Europe GmbH



Front view
Scale: 1:2

Prohibition of the substances of environmental concern

General Tolerances ISO 2768-m

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm
First Angle System

Material & Size	Process	Remark	Type	
8.8		4x necessary		

Scale	Design	Drawn	Checked			Approved	Drw Name	24.-Threaded rod - Both sides
1:2	Jose Romero	Jose Romero					Dwg. or Part no.	

Ref. no.		

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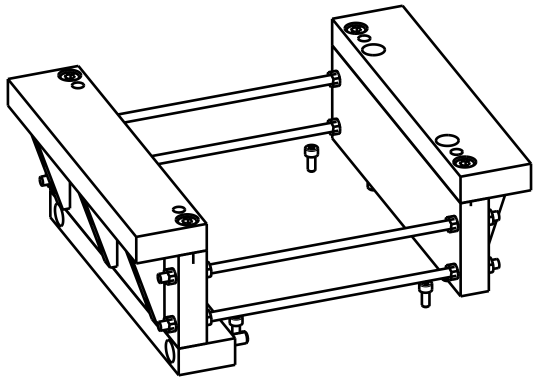
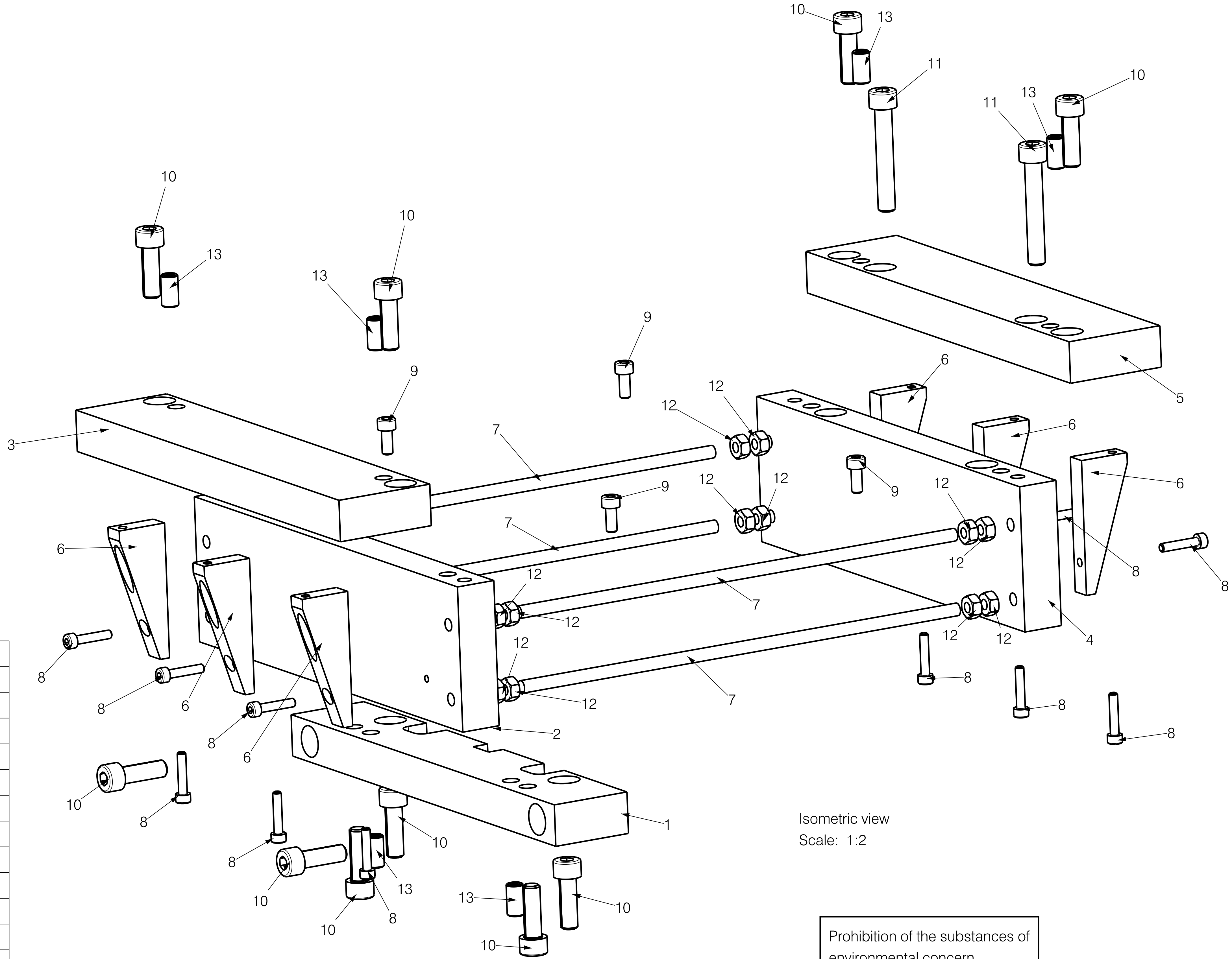
Panasonic Automotive Systems Europe GmbH



3D view
Scale: 1:5



Isometric view
Scale: 1:2

ITEM	QTY	PART NUMBER	MATERIAL
13	6	DIN 7 Φ8h8 x 14	St
12	16	DIN 555 M6	8.8
11	2	DIN 912 M8x50	8.8
10	10	DIN 912 M8x20	8.8
9	4	DIN 912 M5x10	8.8
8	12	DIN 912 M4x16	8.8
7	4	Threaded rod	8.8
6	6	Foot 6	EN AW-2007
5	1	Foot 5	EN AW-2007
4	1	Foot 4	EN AW-2007
3	1	Foot 3	EN AW-2007
2	1	Foot 2	EN AW-2007
1	1	Foot 1	EN AW-2007

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Prohibition of the substances of environmental concern

Unit: mm				Type	
First Angle System	Material & Size	Process	Remark	Drw. Name	25.-Feet Assembly
	Scale	Design	Drawn	Checked	Approved
	1:2	Jose Romero	Jose Romero		
				Dwg. or Part no.	
				Ref. no.	

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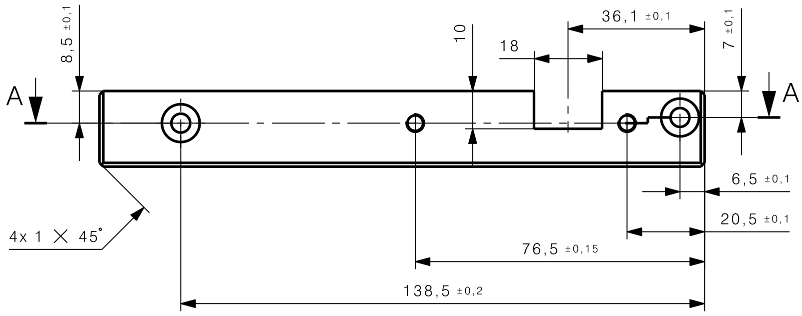
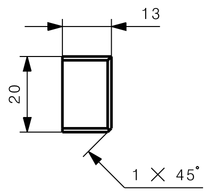
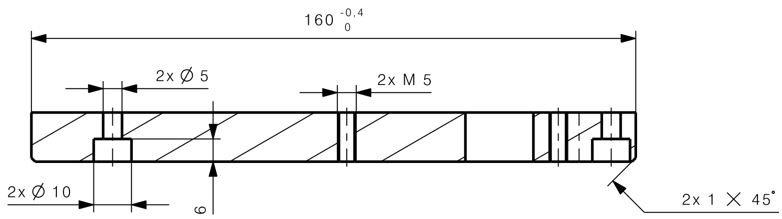
Panasonic Automotive Systems Europe GmbH



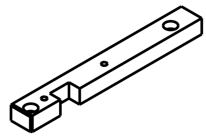
Front view
Scale: 1:2



Left view
Scale: 1:2



Section view A-A
Scale: 1:2



3D view
Scale: 1:5

Chamfer at 0,2x45° the unspecified external edges

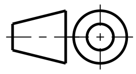
General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm

First Angle System



EN AW-2007			Type	
Material & Size	Process	Remark	Drw Name	26.-Spacer Left

Scale	Design	Drawn	Checked			Approved	Dwg. or Part no.	
1:2	Jose Romero	Jose Romero						

Ref. no.		

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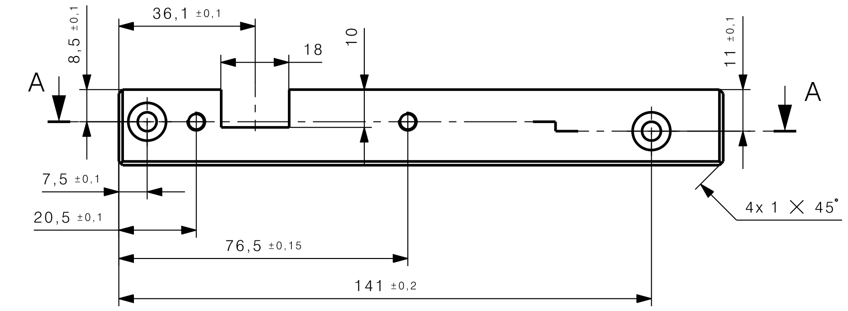
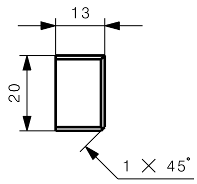
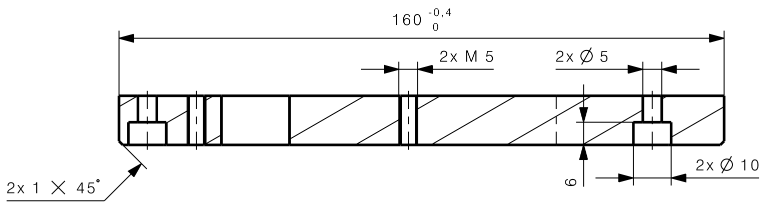
Panasonic Automotive Systems Europe GmbH



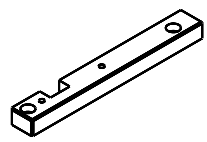
Front view
Scale: 1:2



Left view
Scale: 1:2



Section view A-A
Scale: 1:2



3D view
Scale: 1:5

Chamfer at 0,2x45° the unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm

First Angle System

EN AW-2007			Type	
Material & Size	Process	Remark	Drw Name	27.-Spacer Right
Scale: 1:2	Design: Jose Romero	Drawn: Jose Romero	Checked:	Approved:	Dwg. or Part no.	

Ref. no.		

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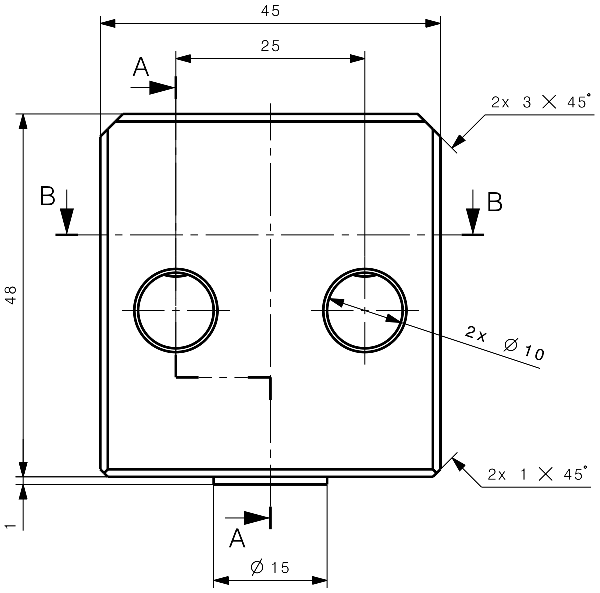
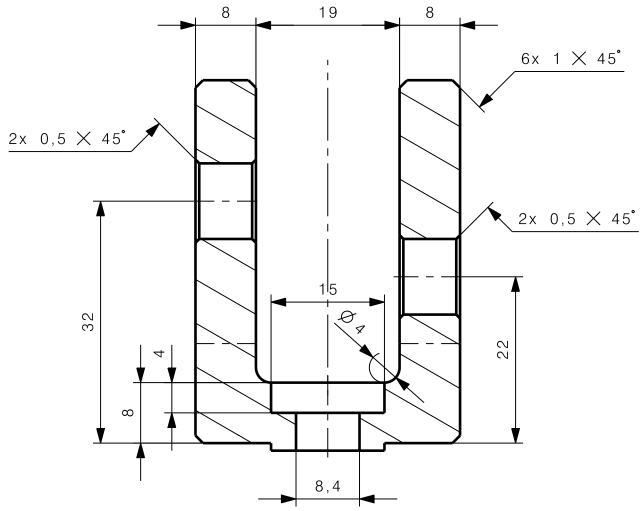
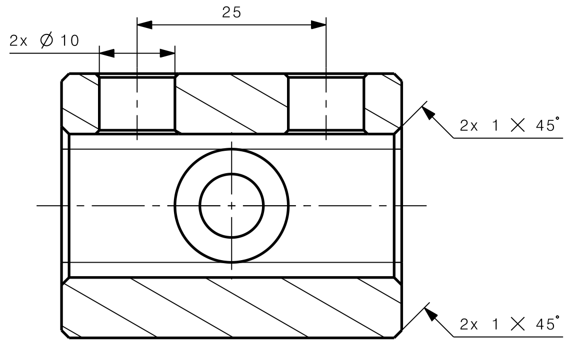
Panasonic Automotive Systems Europe GmbH



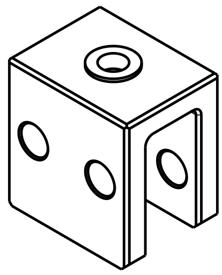
Front view
Scale: 1:1



Section view A-A
Scale: 1:1



Section view B-B
Scale: 1:1



Isometric view
Scale: 1:2

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm
First Angle System

Material & Size	Process	Remark	Type	
EN AW-2007			Drw Name	28.-Load cell end cable fixation v.2
			Dwg. or Part no.	

Scale	Design	Drawn	Checked	Approved
1:1	Jose Romero	Jose Romero		

Ref. no.		

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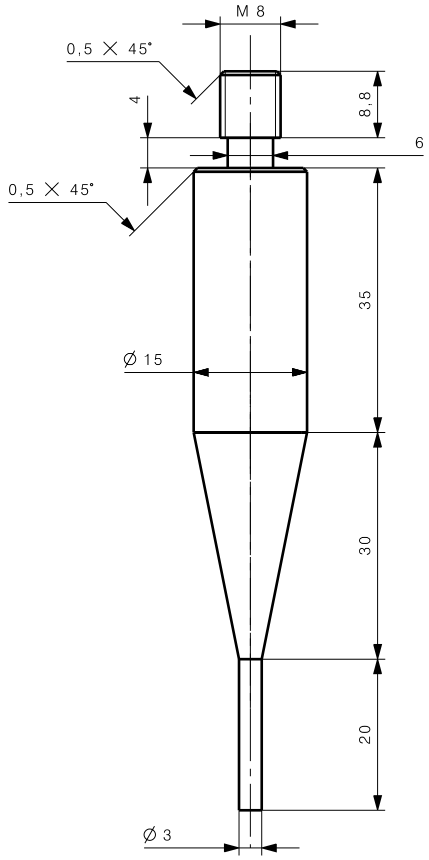
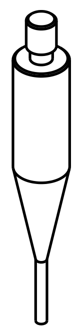
Panasonic Automotive Systems Europe GmbH



Front view
Scale: 1:1



Isometric view
Scale: 1:2

Prohibition of the substances of environmental concern

General Tolerances ISO 2768-m

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm
First Angle System

Material & Size	Process	Remark	Type	
S235JR			Drw Name	29.-Load cell end. Pin test

Scale	Design	Drawn	Checked	Approved	Dwg. or Part no.
1:1	Jose Romero	Jose Romero			

Ref. no.

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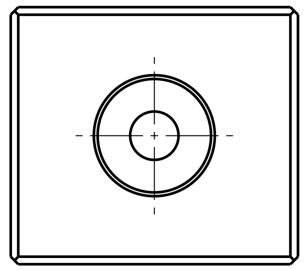
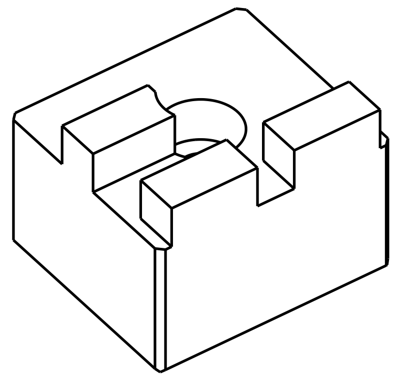
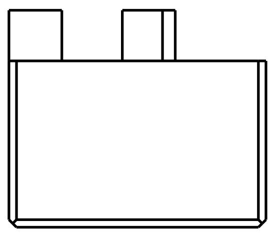


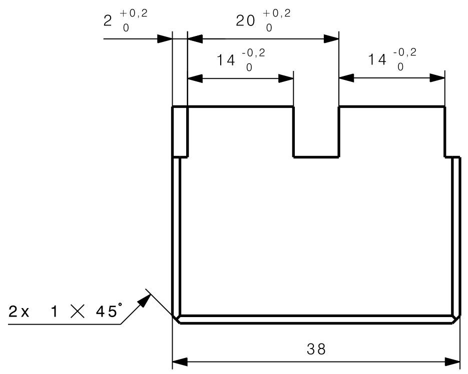
Bottom view
Scale: 1:1



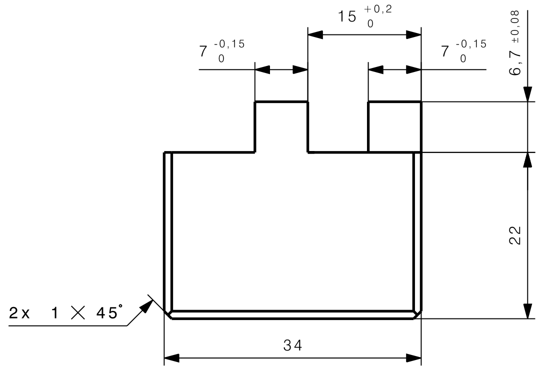
3D view
Scale: 1:1



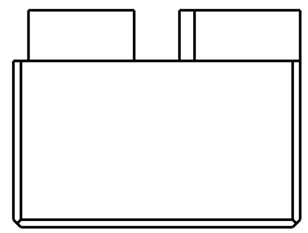
Right view
Scale: 1:1



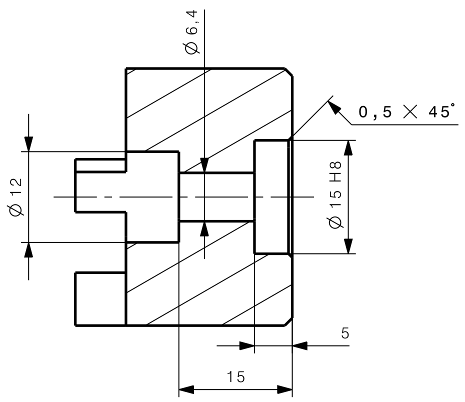
Front view
Scale: 1:1



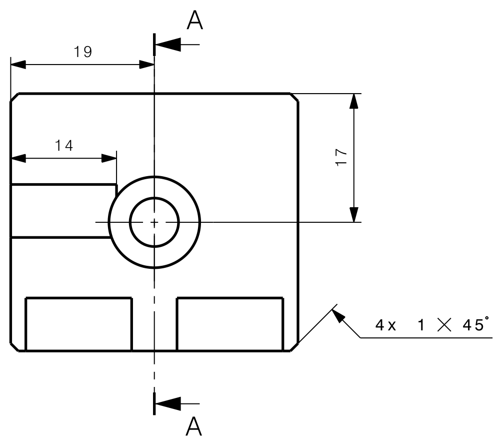
Left view
Scale: 1:1



Rear view
Scale: 1:1



Section view A-A
Scale: 1:1



Top view
Scale: 1:1

Chamfer at 0,2x45° the unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm	EN AW-2007				Type	
First Angle System	Material & Size	Process		Remark	Drw. Name	30.-Load cell end plug test MIB
	Scale	Design	Drawn	Checked	Approved	
	1:1	Jose Romero	Jose Romero		Dwg. or Part no.	

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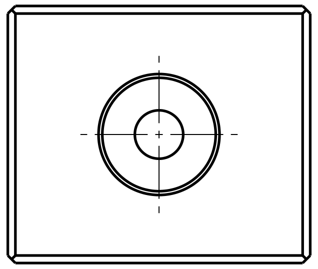
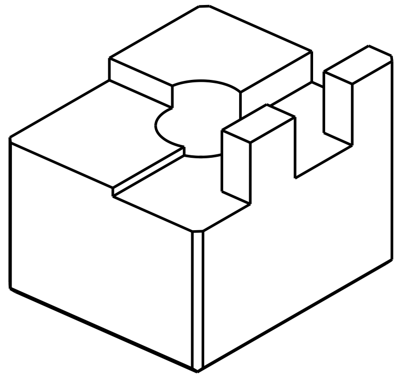
Ref. no.	

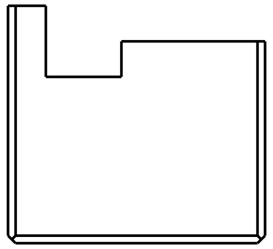
Panasonic Automotive Systems Europe GmbH



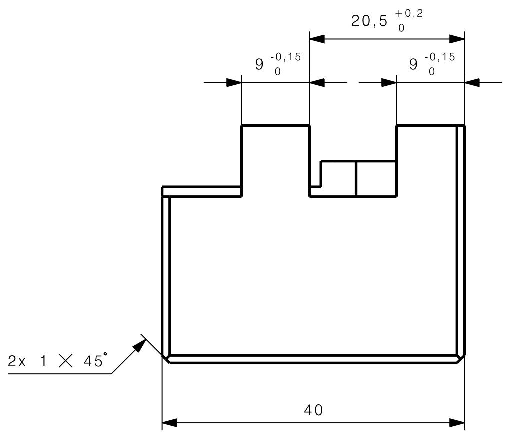
Bottom view
Scale: 1:1



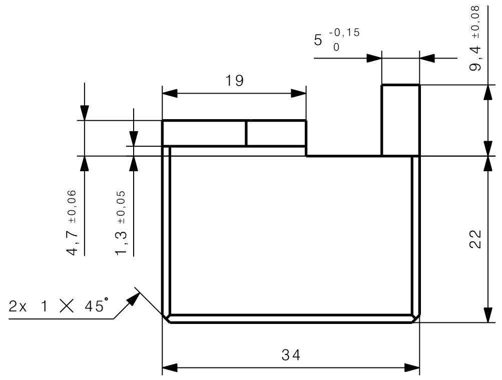
Isometric view
Scale: 1:1



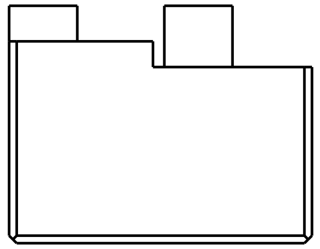
Right view
Scale: 1:1



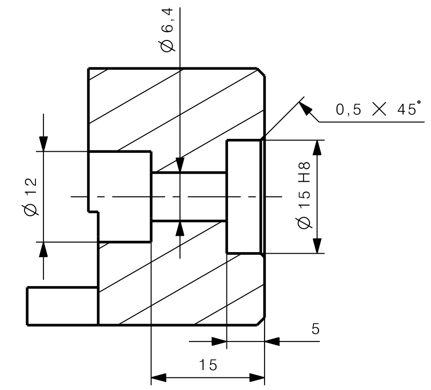
Front view
Scale: 1:1



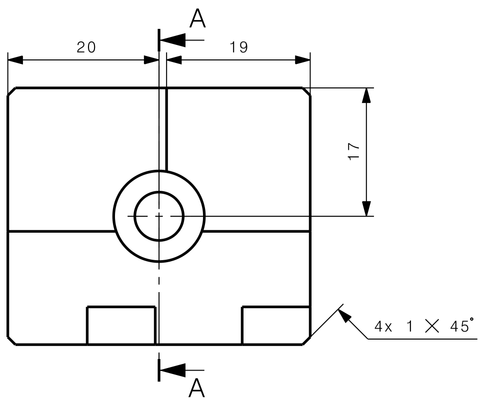
Left view
Scale: 1:1



Rear view
Scale: 1:1



Section view A-A
Scale: 1:1



Top view
Scale: 1:1

```
Chamfer at 0,2x45° the
unspecified external edges

General Tolerances ISO 2768-m
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Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm	EN AW-2007			Type	
First Angle System	Material & Size	Process	Remark	Drw. Name	31.-Load cell end plug test
	Scale	Design	Drawn	Checked	Approved
	1:1	Jose Romero	Jose Romero		Dwg. or Part no.

Ref. no.	

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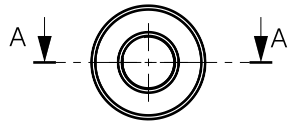
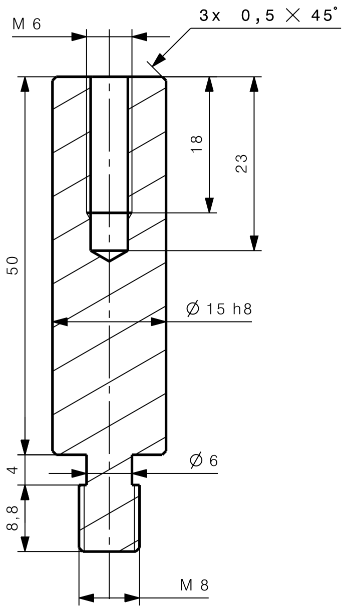
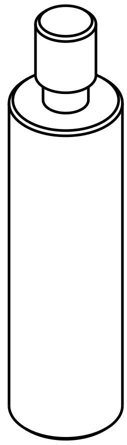
Panasonic Automotive Systems Europe GmbH



Front view
Scale: 1:1



Section view A-A
Scale: 1:1



Isometric view
Scale: 1:1

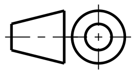
Chamfer at 0,2x45° the
unspecified external edges

General Tolerances ISO 2768-m

Prohibition of the substances of environmental concern

Sym.	Date	Revision	Checked	Approved
3				
2				
1				

Unit: mm
First Angle System



Material & Size	Process	Remark		
S235JR			Type	
			Drw Name	32.-Load cell end connection

Scale	Design	Drawn	Checked	Approved		
1:1	Jose Romero	Jose Romero			Dwg. or Part no.	

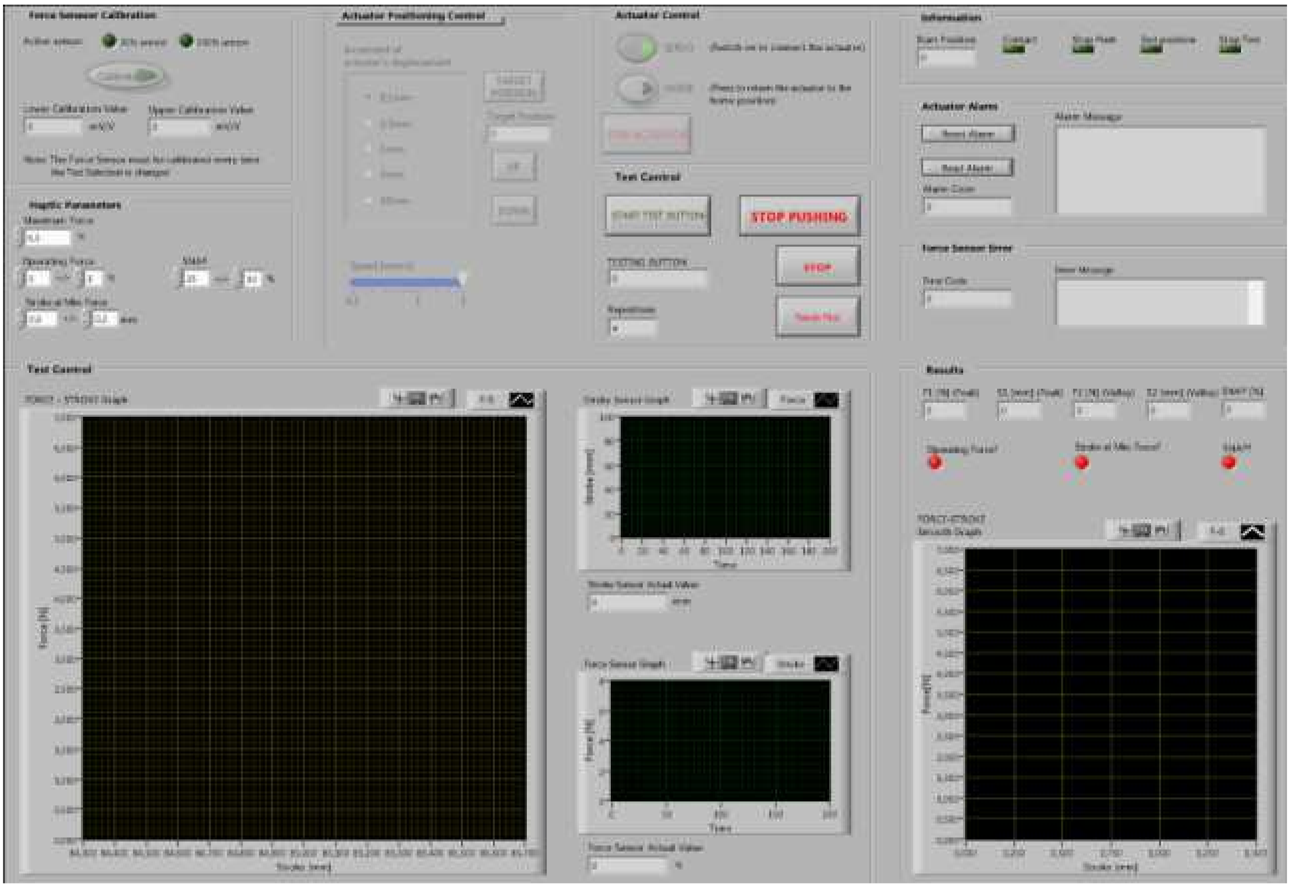
Ref. no.		

--CONFIDENTIAL--

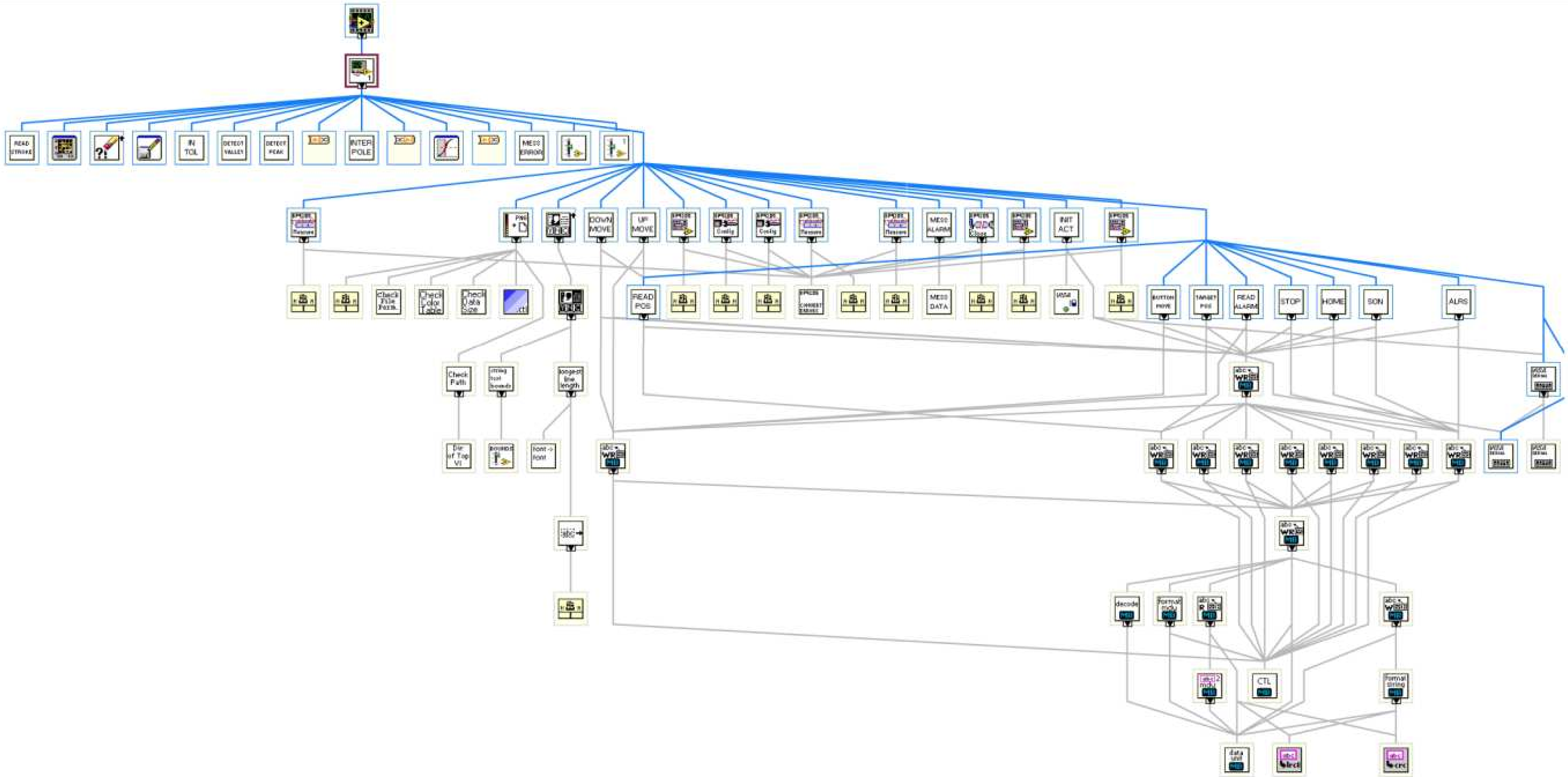
Panasonic Automotive Systems Europe GmbH

D. API front panel and block diagram

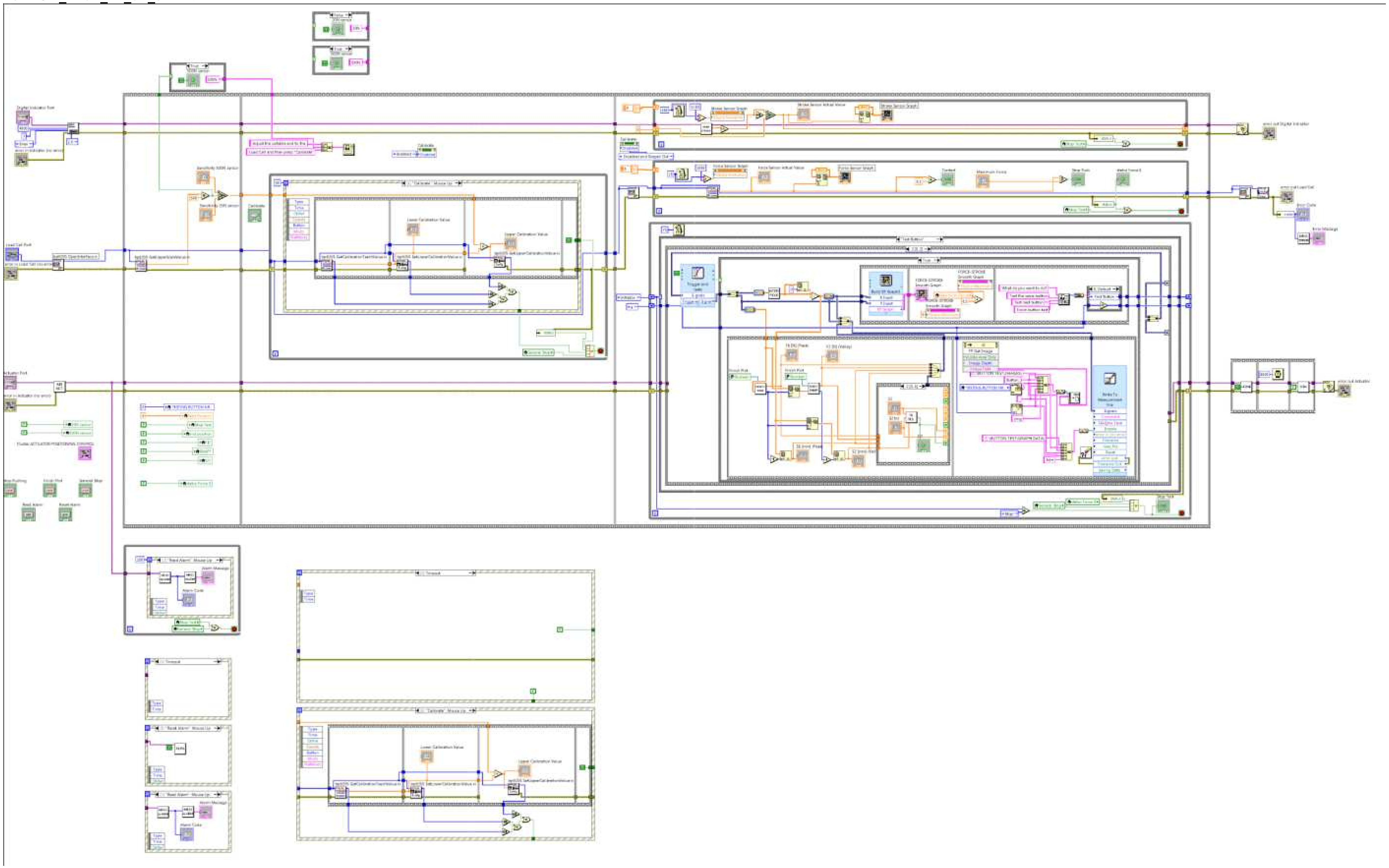
Front panel



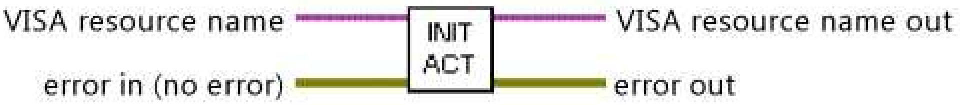
BUTTON_TEST_F1_S2_SNAP Hierarchy

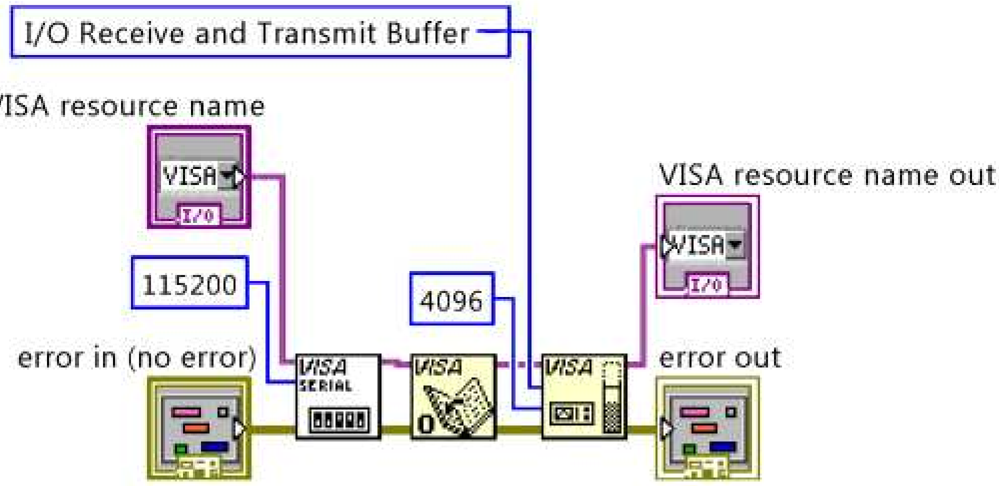


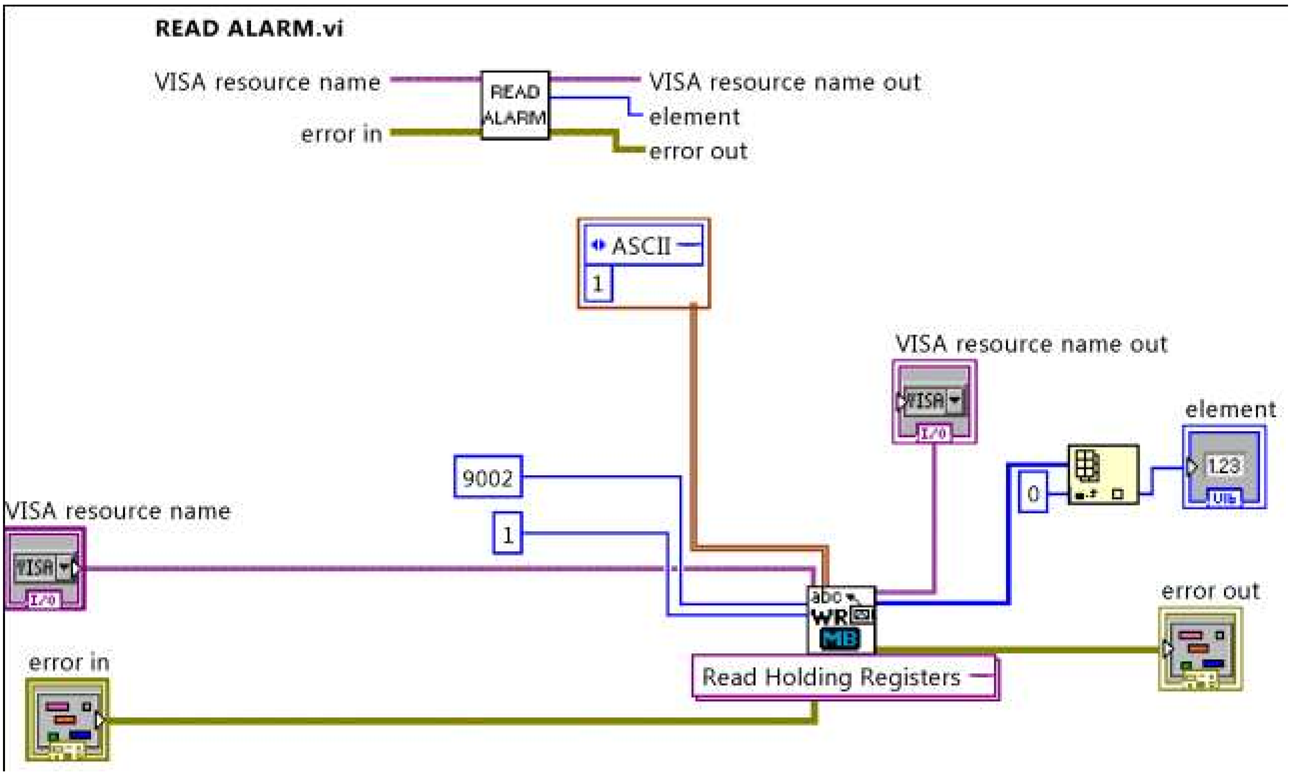
BUTTON_TEST_F1_S2_SNAP.vi



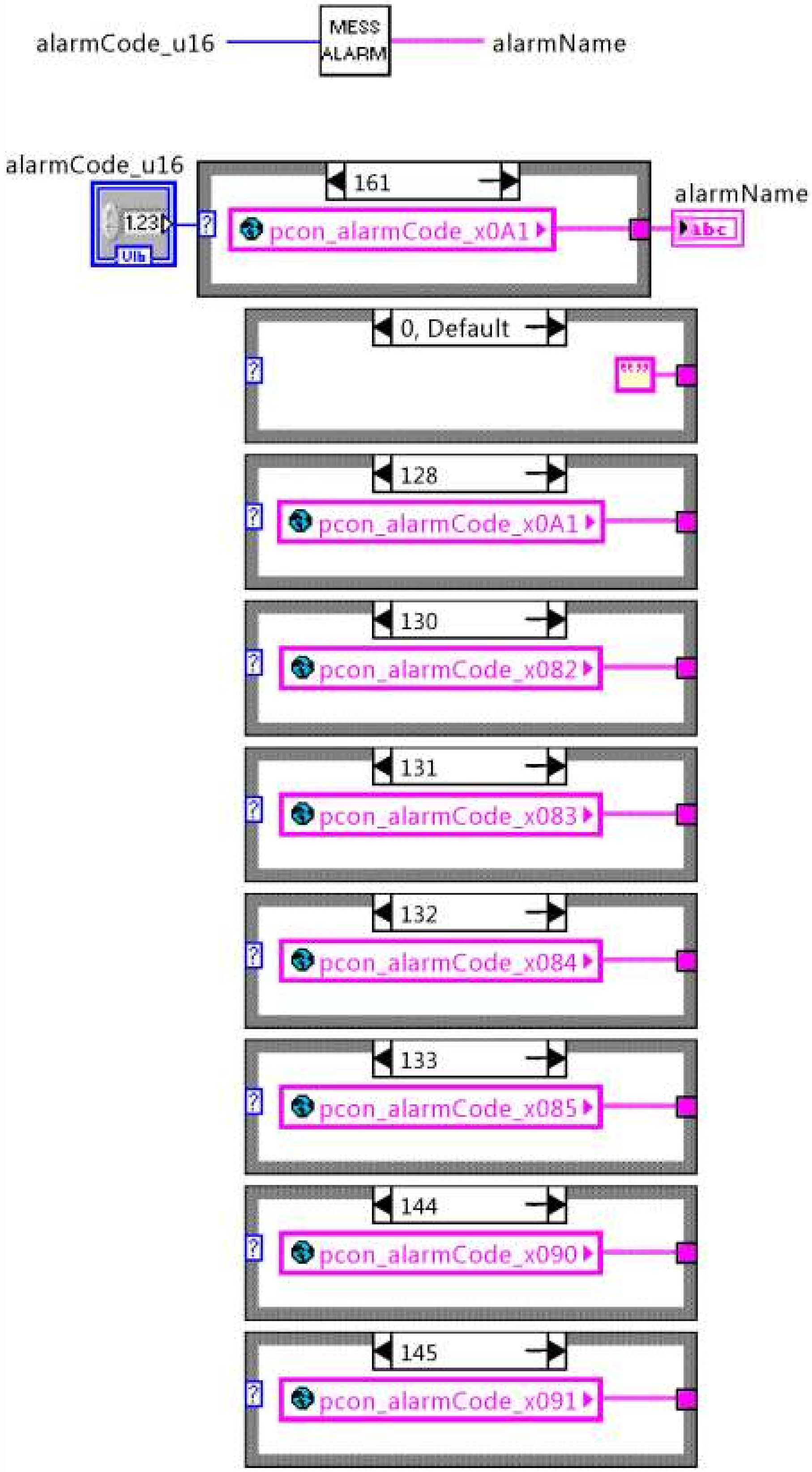
INIT ACT.vi


VISA resource name
error in (no error)
INIT ACT
VISA resource name out
error out

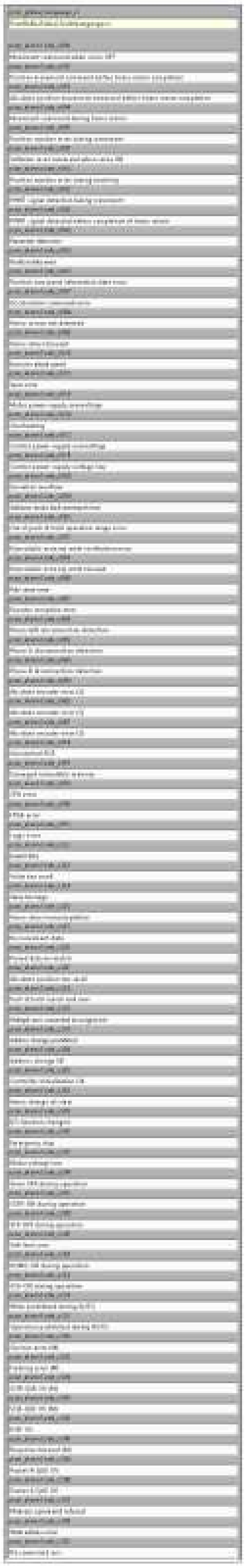

I/O Receive and Transmit Buffer
VISA resource name
VISA
I/O
115200
4096
error in (no error)
VISA SERIAL
VISA
0
VISA
VISA resource name out
error out

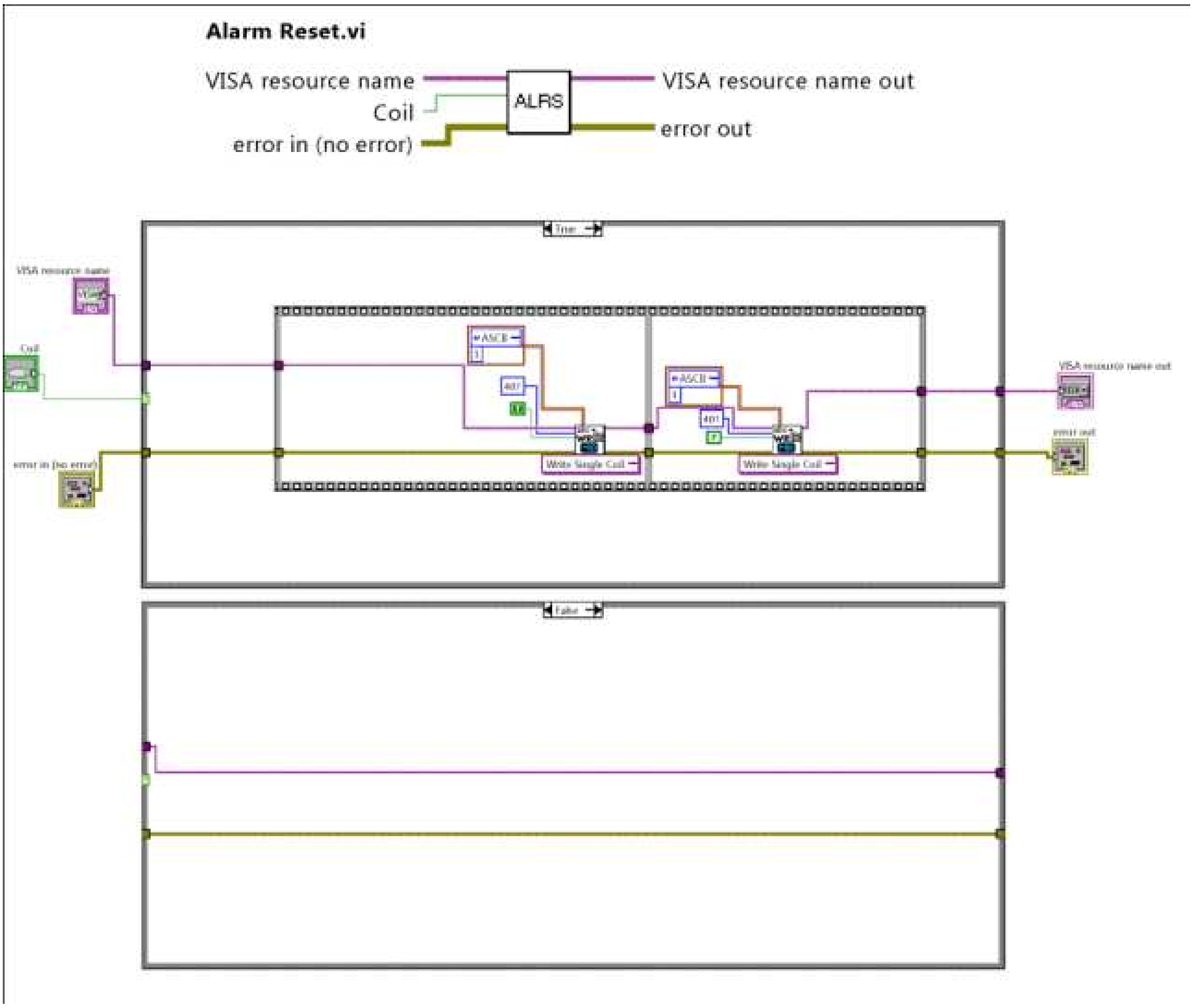

READ ALARM.vi
VISA resource name
error in
READ ALARM
VISA resource name out
element
error out
ASCII
1
VISA resource name out
element
9002
1
0
123
VISA resource name
VISA
error in
Read Holding Registers
error out

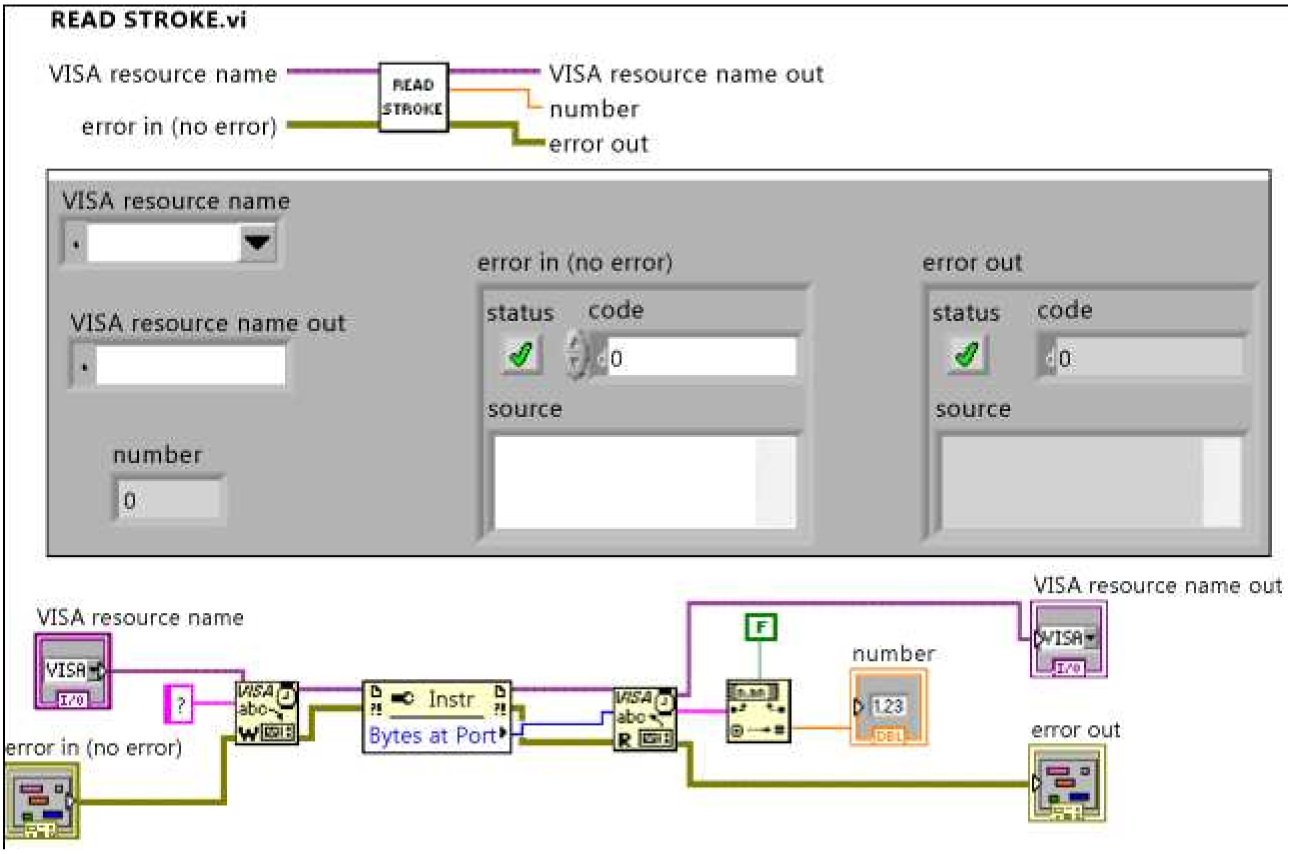
MESS ALARM.vi



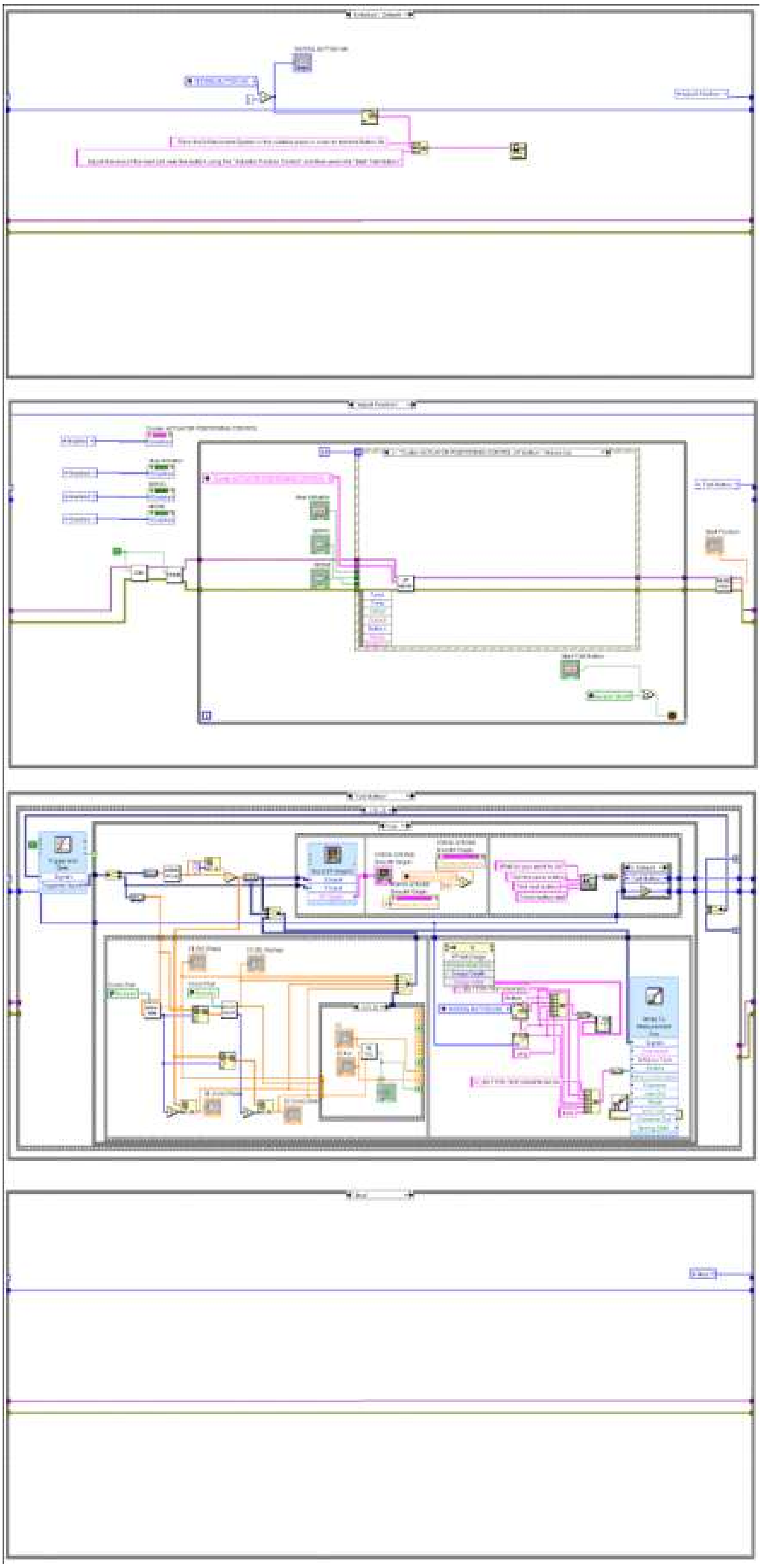
MESS DATA.vi



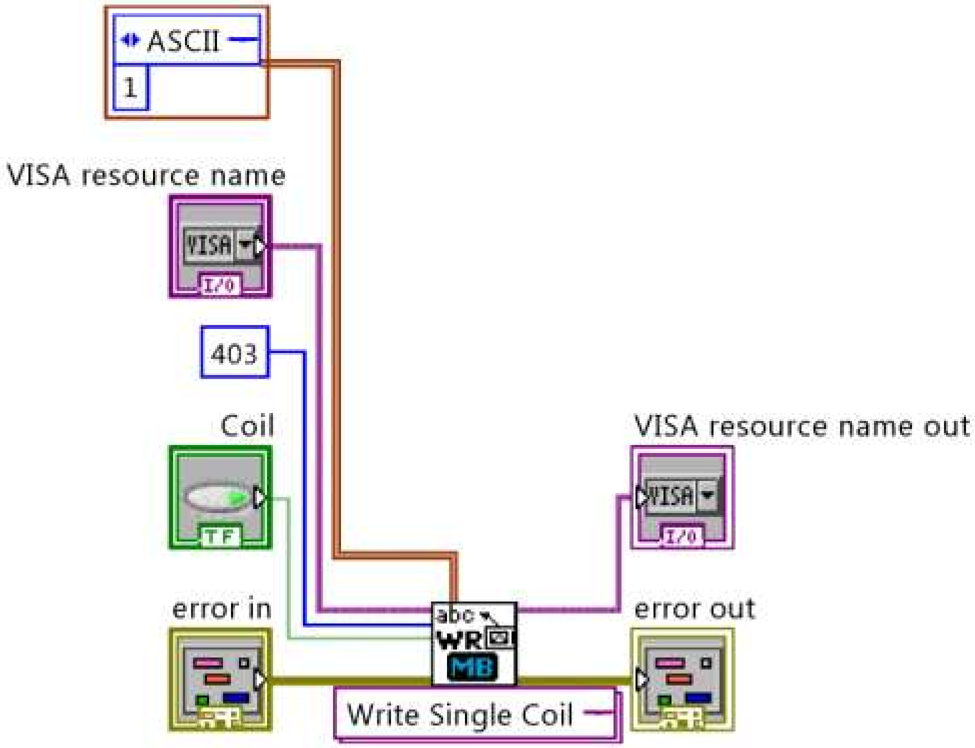

Alarm Reset.vi
VISA resource name
Coil
error in (no error)
ALRS
VISA resource name out
error out
Write Single Coil
Write Single Coil


READ STROKE.vi
VISA resource name
error in (no error)
READ STROKE
VISA resource name out
number
error out
VISA resource name
error in (no error)
error out
status
code
0
source
VISA resource name out
number
0
VISA resource name
VISA
?
Instr
Bytes at Port
F
number
1.23
DBL
VISA resource name out
error in (no error)
error out

Test case structure



ON_OFF Servo.vi



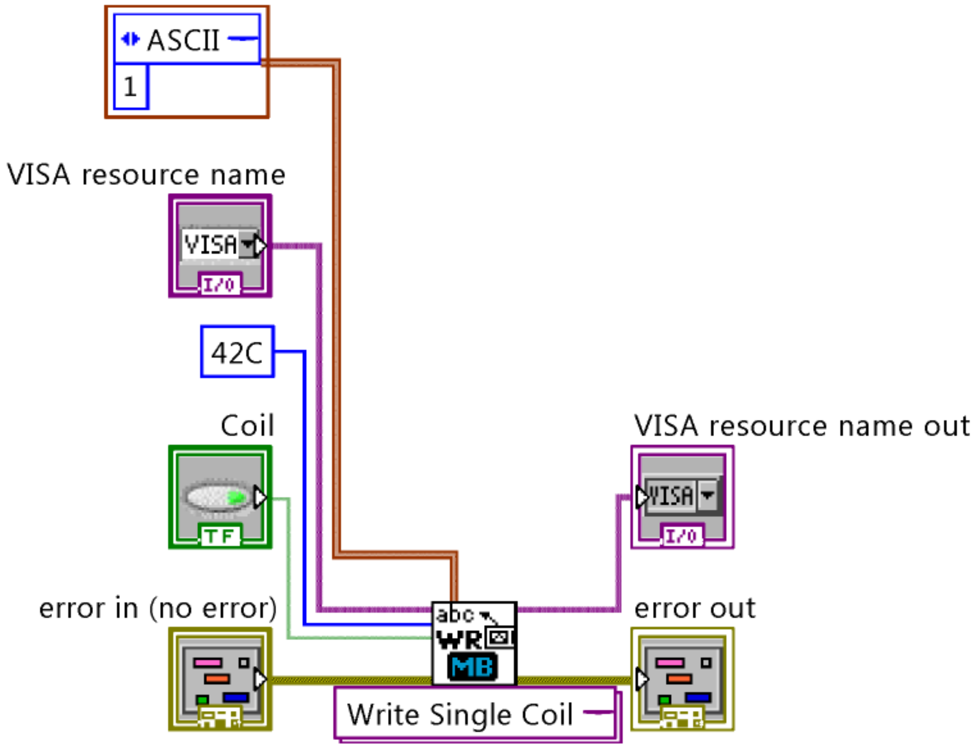
HOME.vi

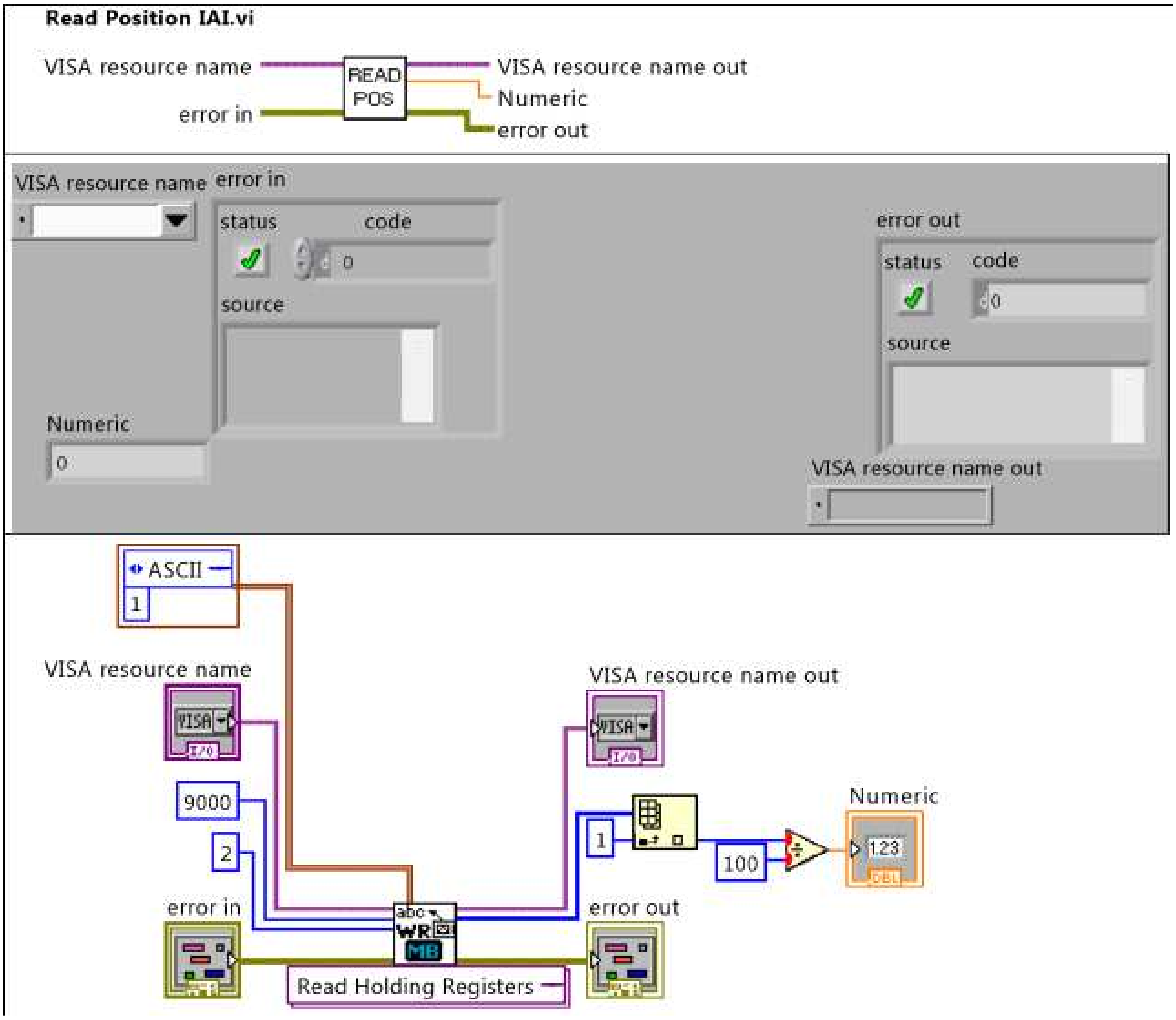

VISA resource name
Coil
error in (no error)
HOME
VISA resource name out
error out


True
False
ASCII
408
Write Single Coil

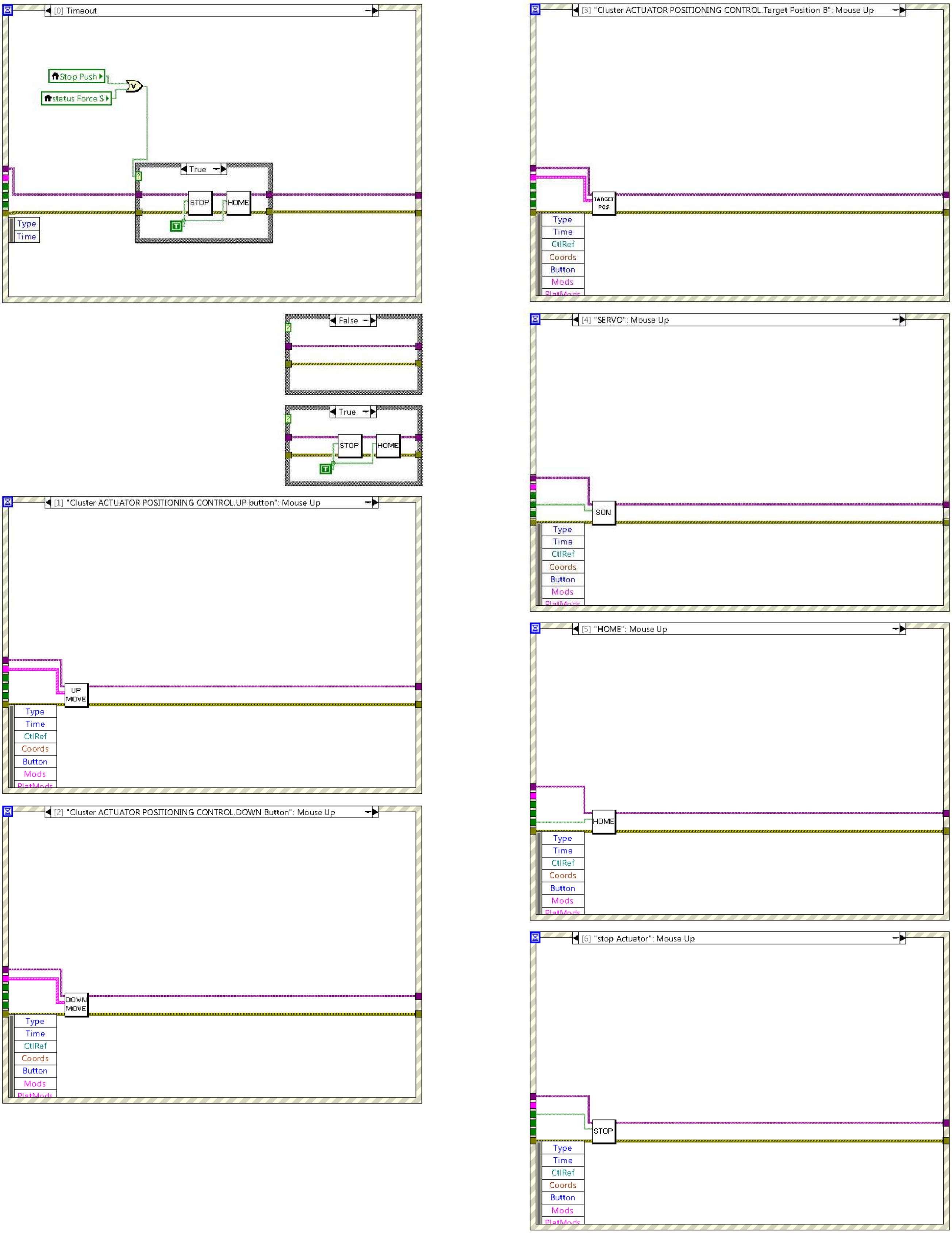
STOP.vi


VISA resource name
Coil
error in (no error)
STOP
VISA resource name out
error out

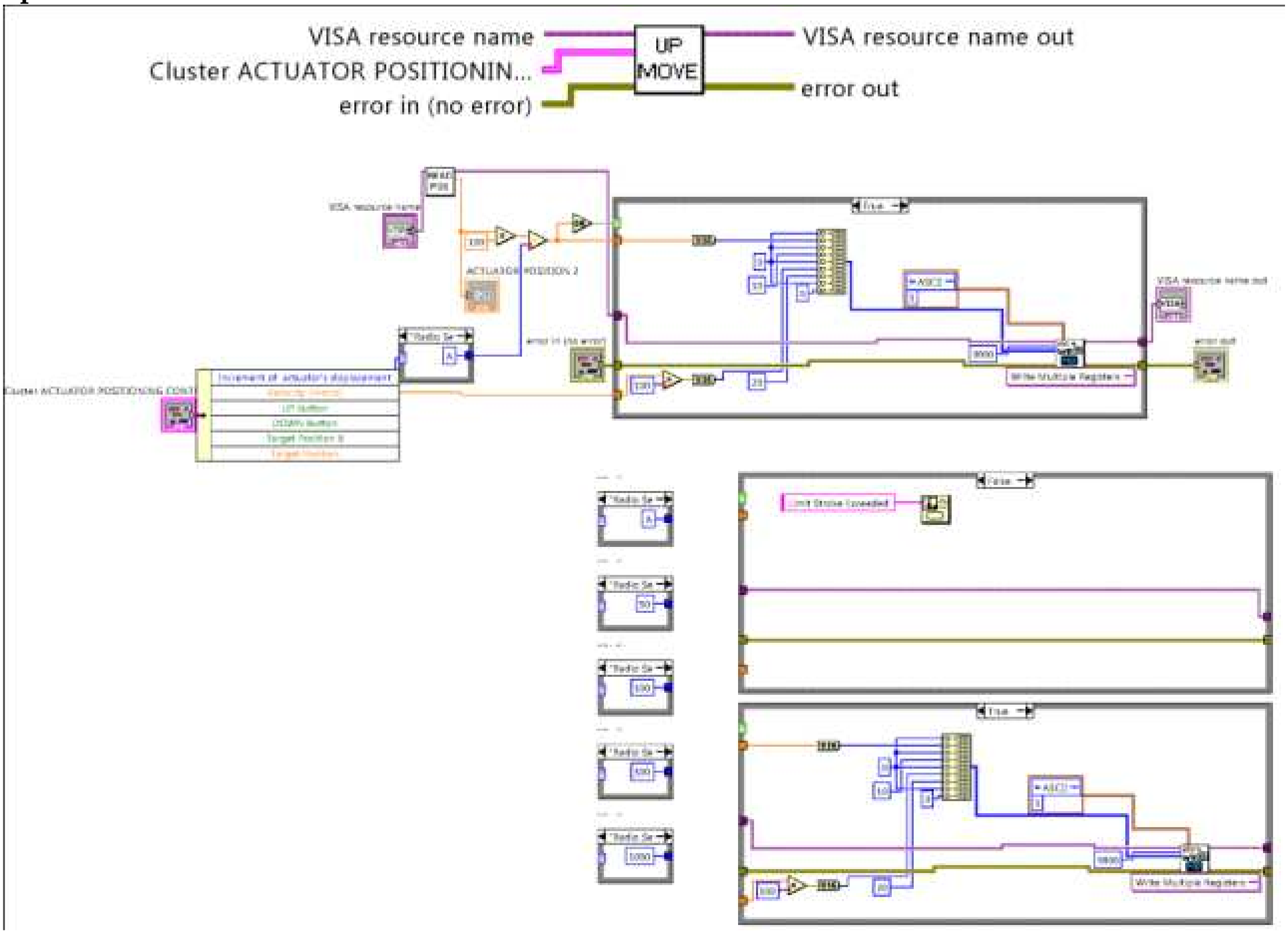

ASCII
1
VISA resource name
VISA
I/O
42C
Coil
TF
error in (no error)
abc
WR
MB
Write Single Coil
VISA resource name out
VISA
I/O
error out


Read Position IAI.vi
VISA resource name
error in
READ POS
VISA resource name out
Numeric
error out
VISA resource name
error in
status
code
0
source
Numeric
0
error out
status
code
0
source
VISA resource name out
ASCII
1
VISA resource name
VISA
9000
2
error in
WR
MB
Read Holding Registers
VISA resource name out
VISA
1
100
Numeric
123
DBL
error out

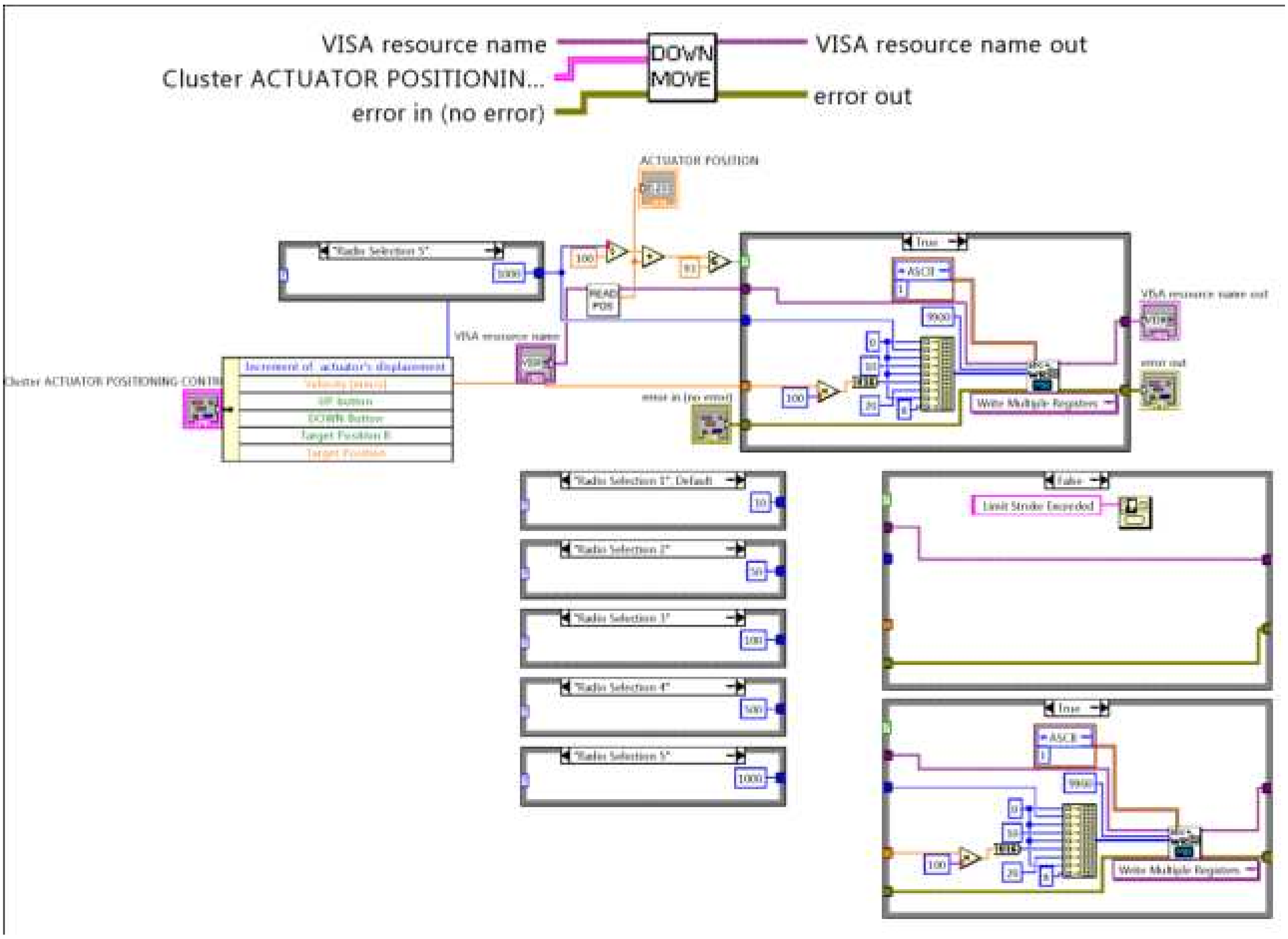
Adjust position event structure



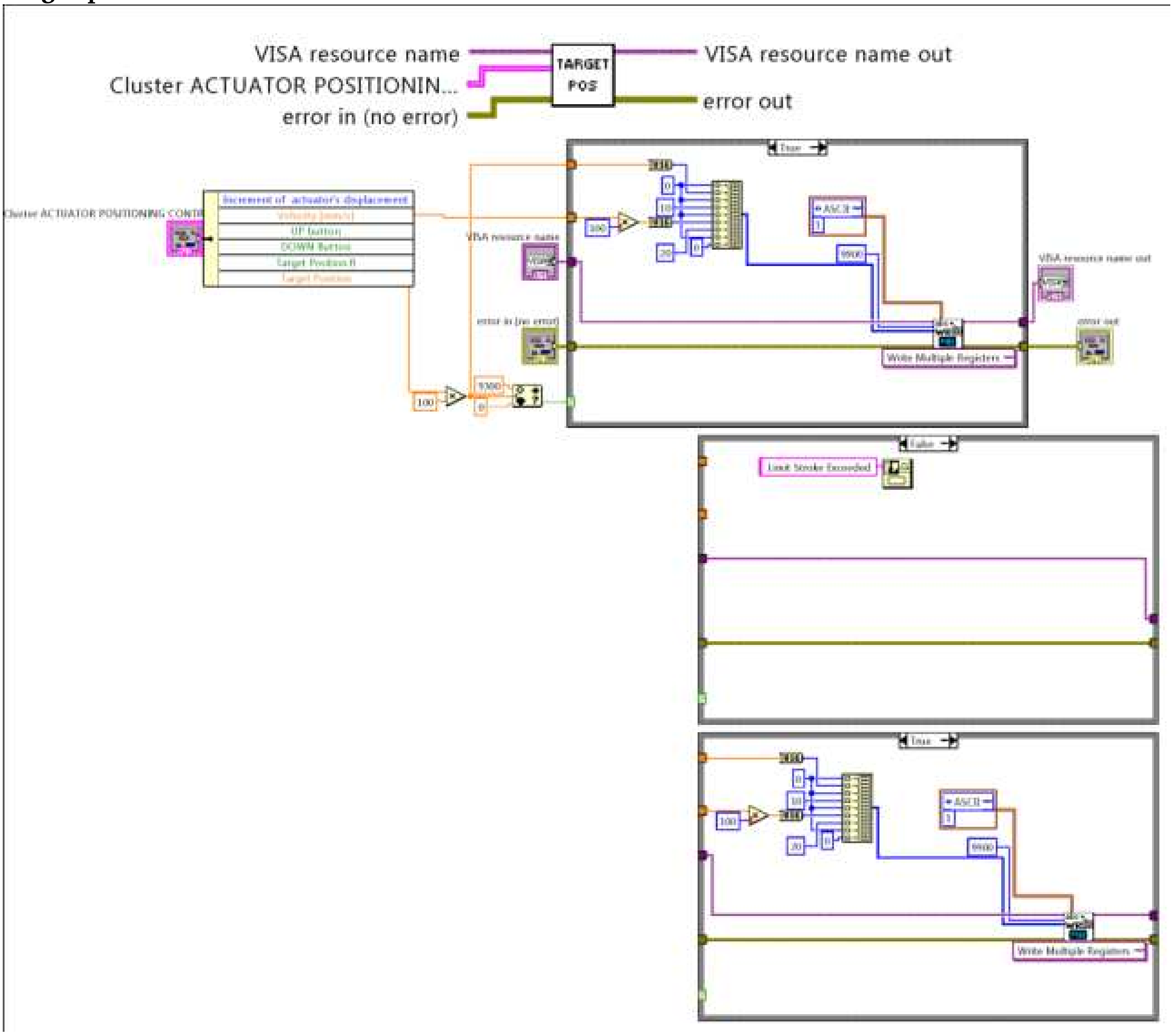
Up movement


VISA resource name
Cluster ACTUATOR POSITIONIN...
error in (no error)
UP
MOVE
VISA resource name out
error out
True
False
ASCII
Write Multiple Registers
Increment of actuator's displacement
UP Button
DOWN Button
Target Position
Limit Stroke Exceeded

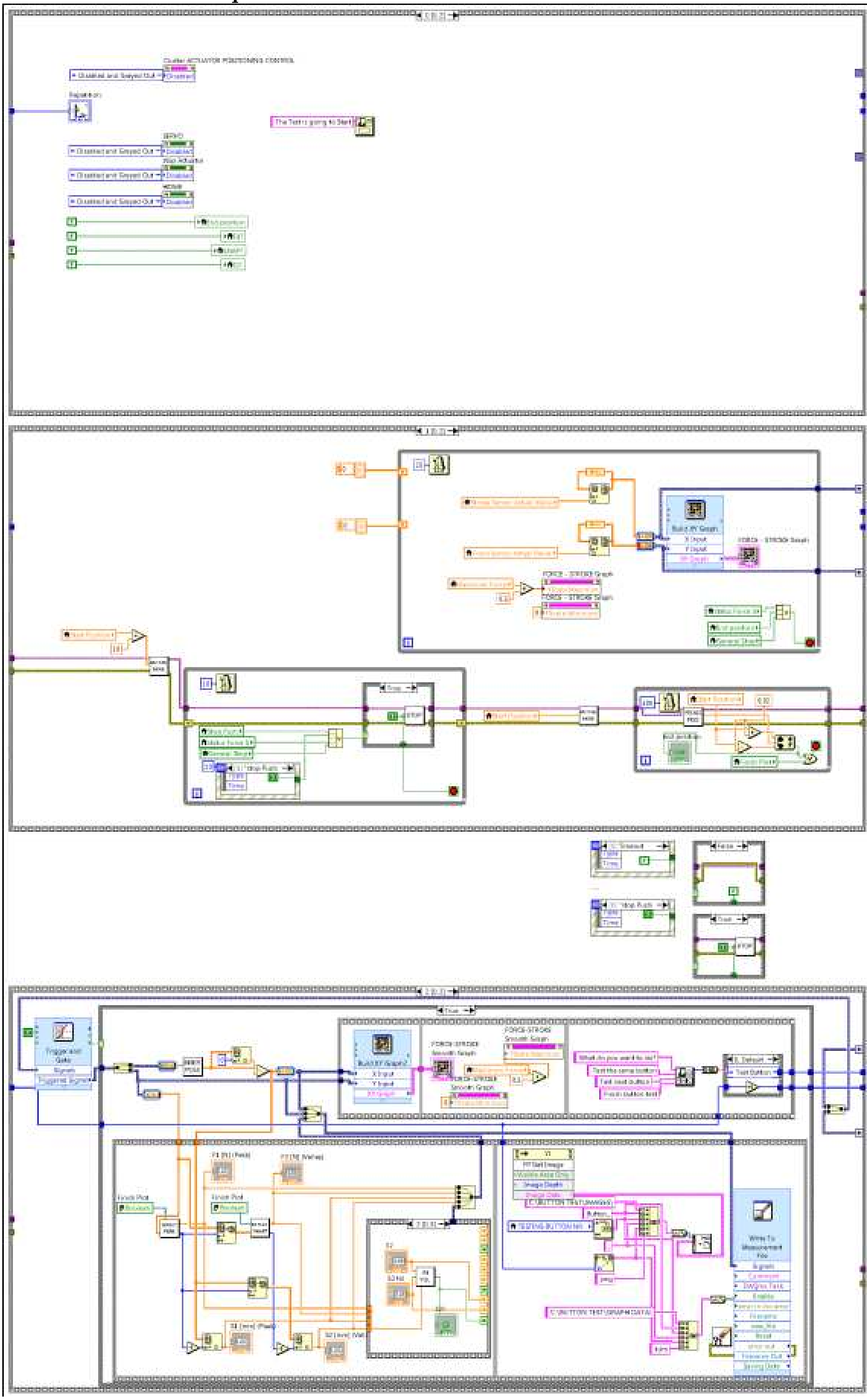
Down movement

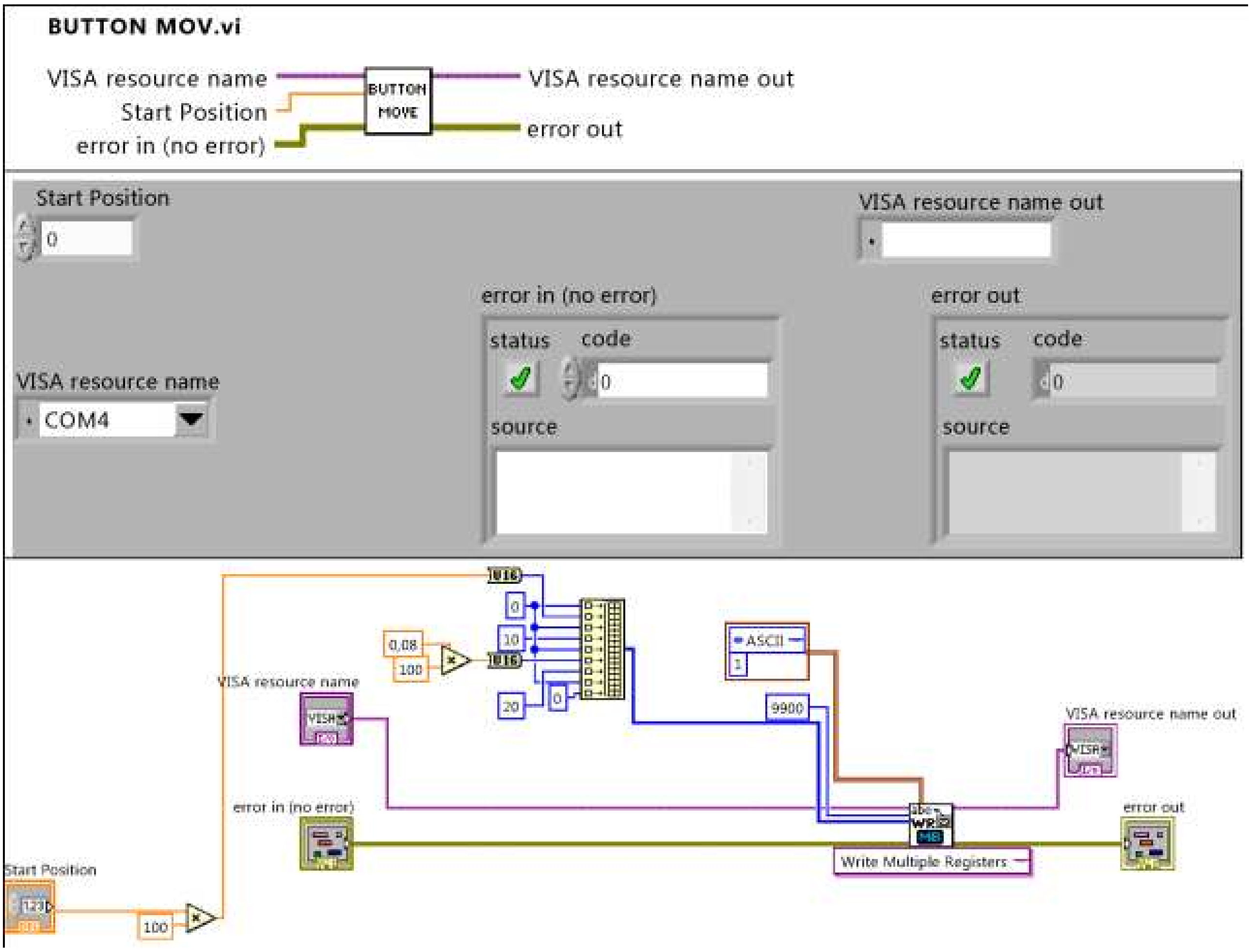


Target position

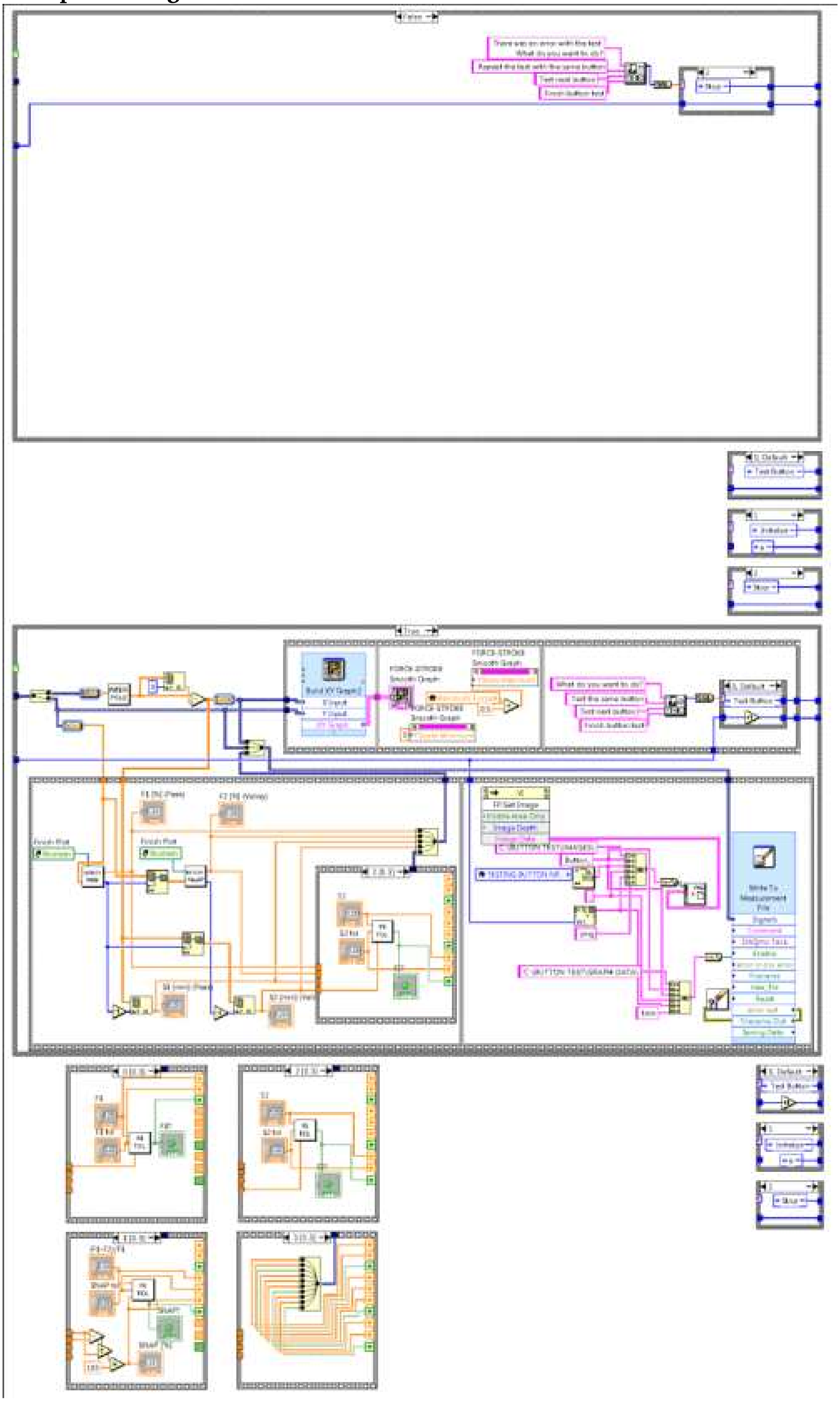


Test button stacket sequence structure

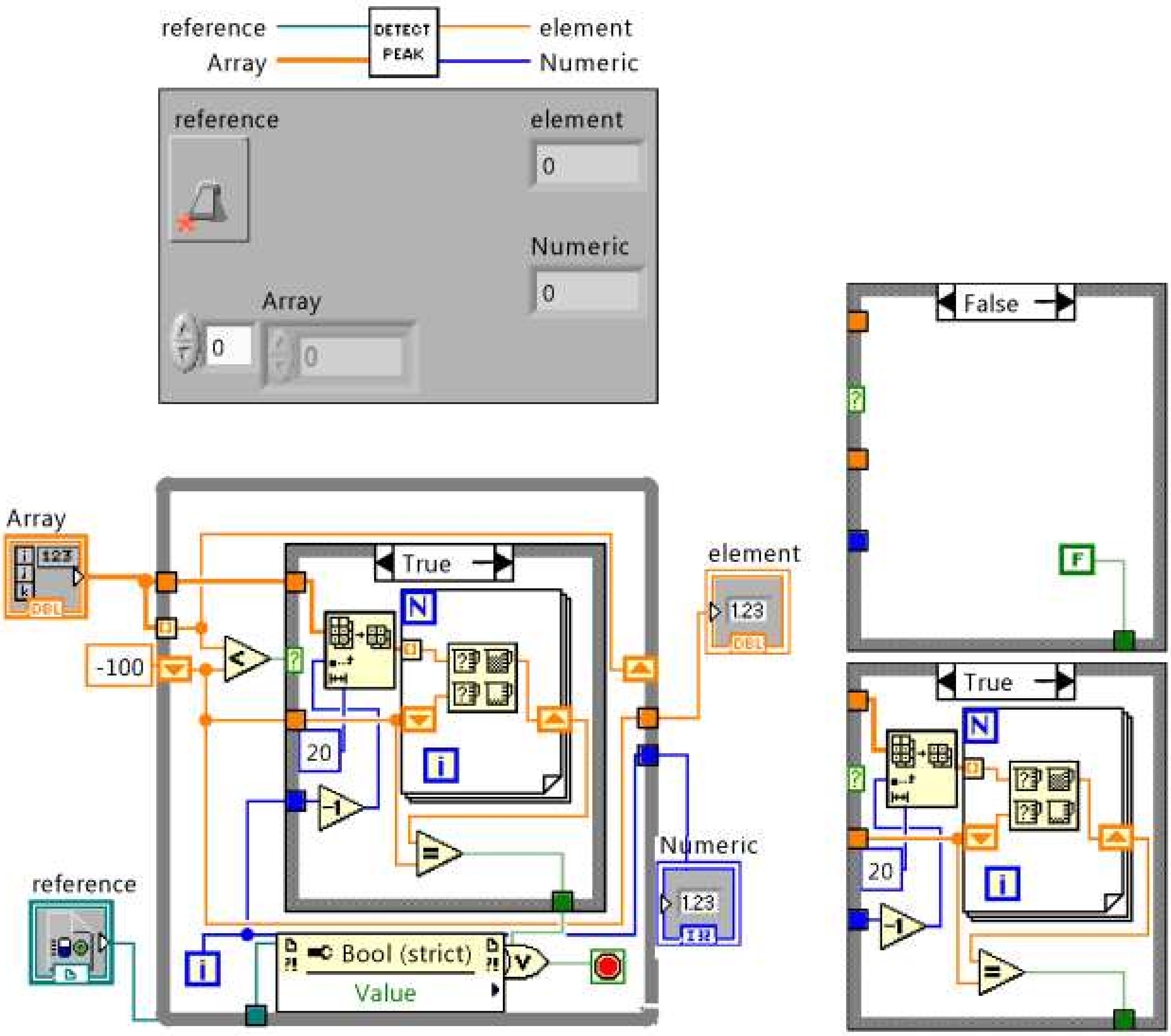


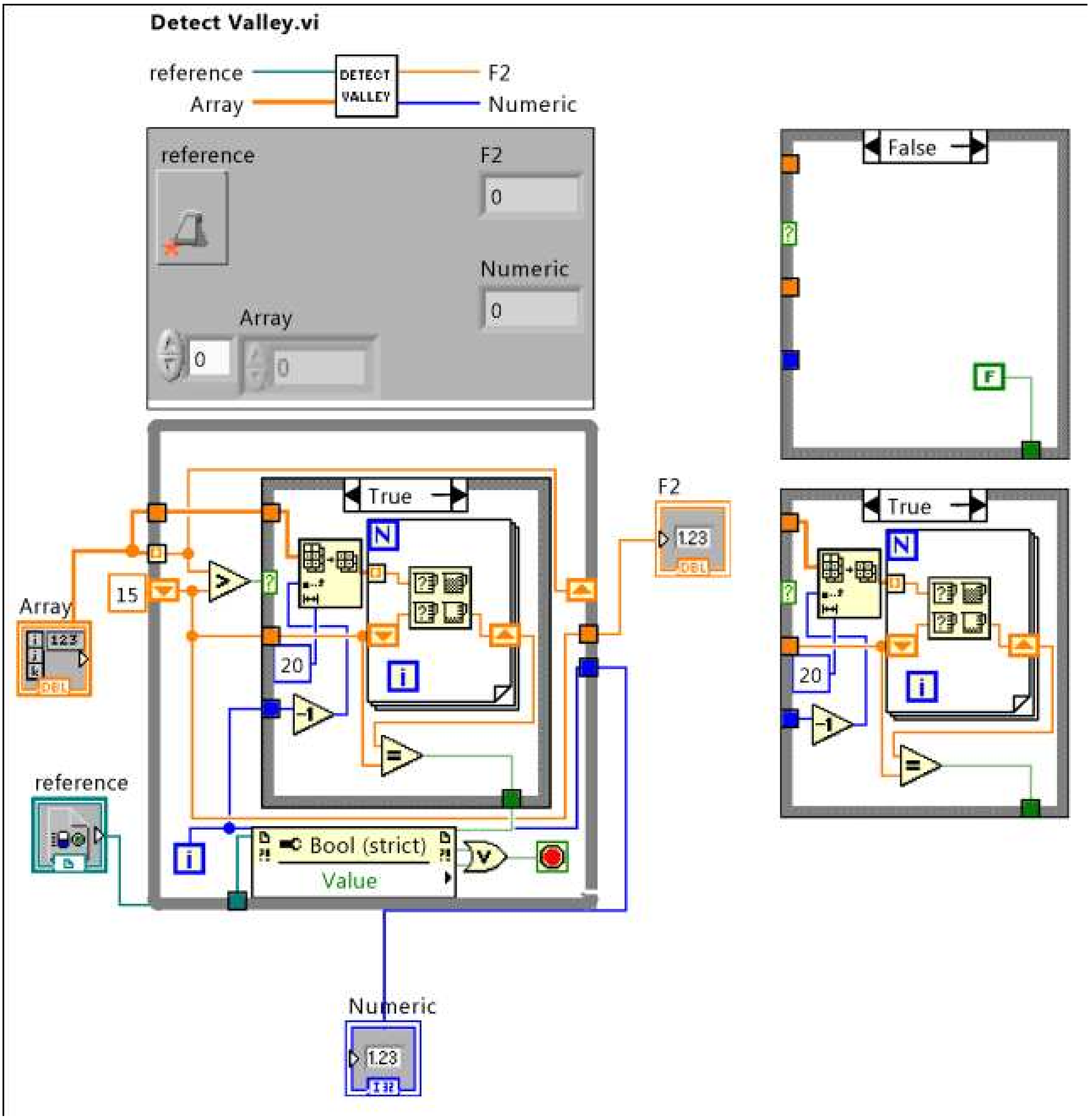

BUTTON MOV.vi
VISA resource name
Start Position
error in (no error)
BUTTON MOVE
VISA resource name out
error out
Start Position
0
VISA resource name out
error in (no error)
error out
status
code
0
source
VISA resource name
COM4
U16
0
10
0,08
100
20
ASCII
1
9900
Write Multiple Registers
100

Data processing case structure



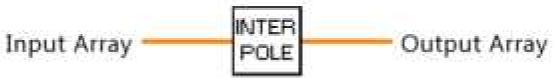
Detect Peak.vi

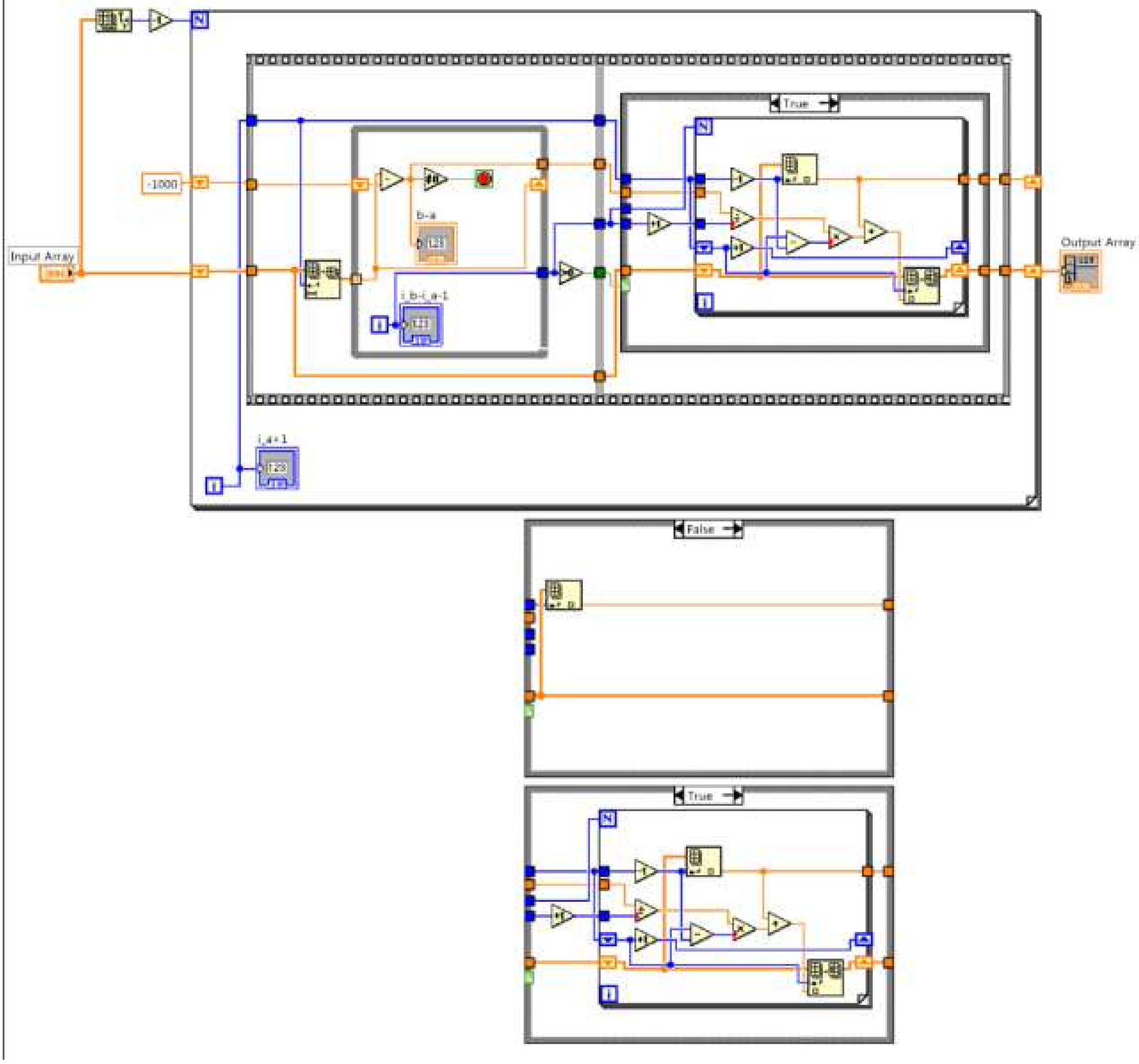




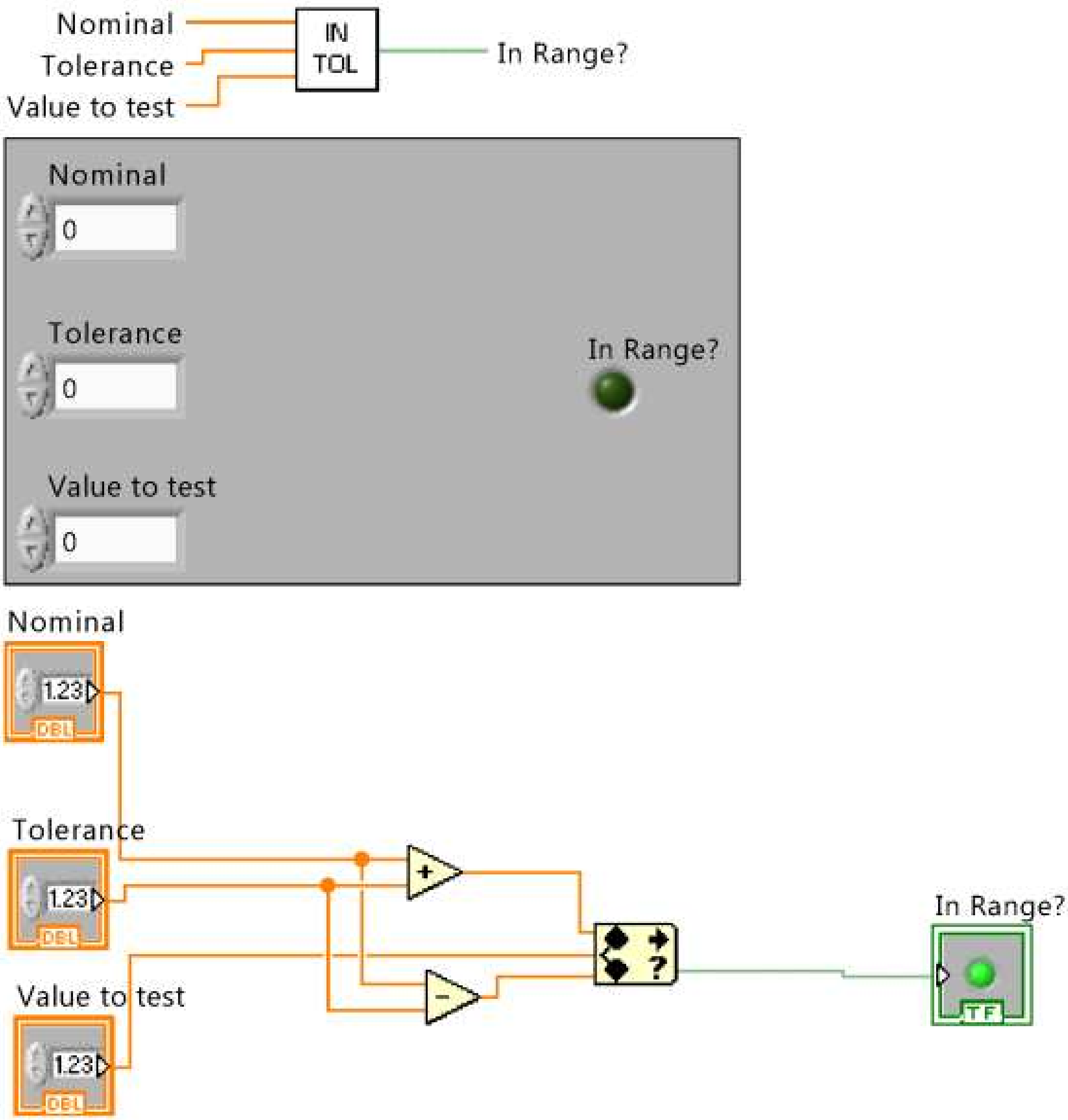
Detect Valley.vi
reference
Array
DETECT VALLEY
F2
Numeric
reference
F2
0
Numeric
0
Array
0
0
False
F
True
True
Array
15
20
reference
Bool (strict)
Value
F2
Numeric
20

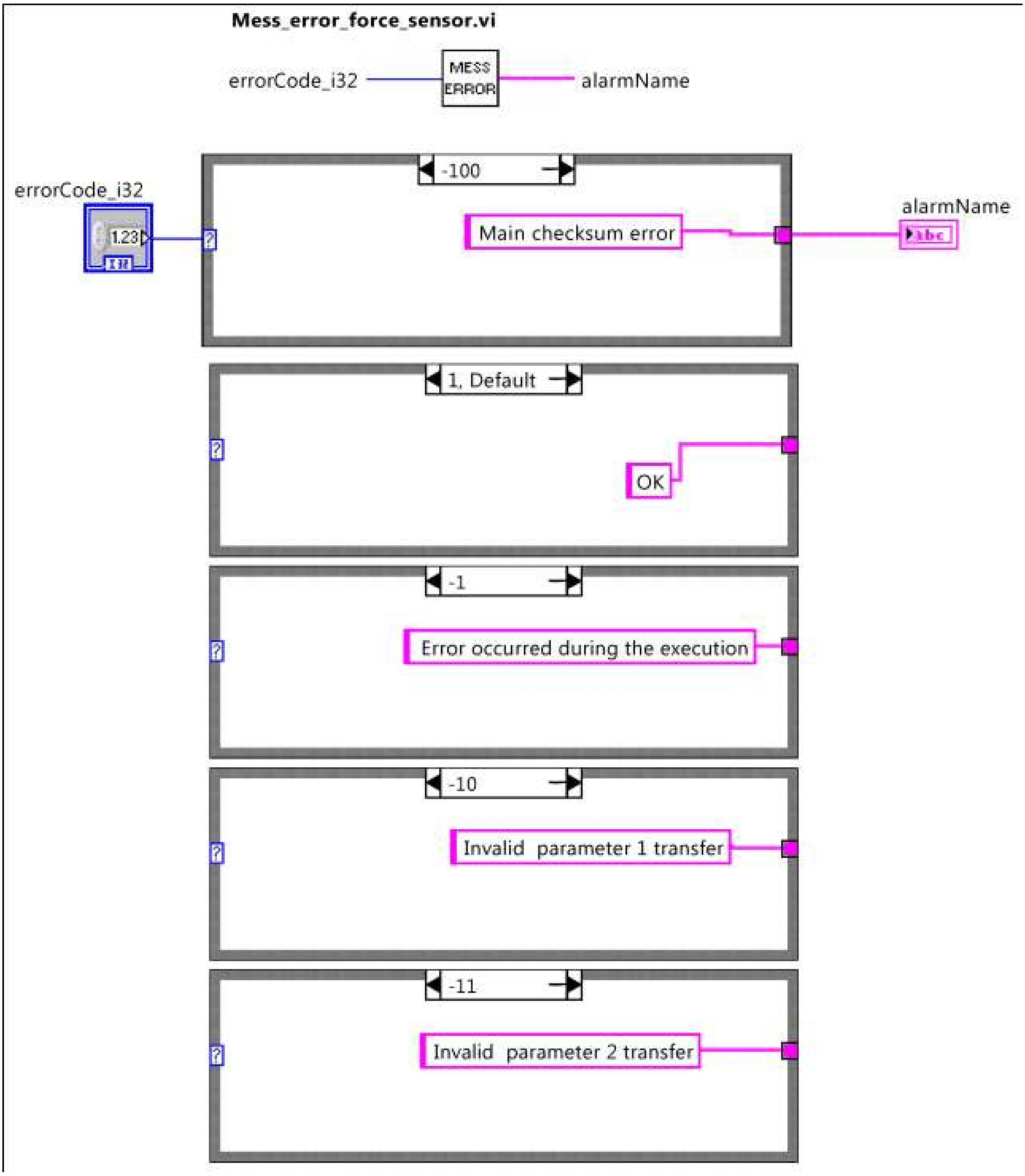
Interpole.vi





Inside Tolerance.vi





Mess_error_force_sensor.vi
errorCode_i32
MESS
ERROR
alarmName
errorCode_i32
1.23
I32
-100
Main checksum error
alarmName
abc
1, Default
OK
-1
Error occurred during the execution
-10
Invalid parameter 1 transfer
-11
Invalid parameter 2 transfer

E. Evaluation's tests

Repeatability test

Button	Button repetition	F1 [N]	Operating Force?	F2 [N]	SNAP [%]	SNAP?	S2 [mm]	Stroke at min force?	S1 [mm]
4	Button_1_a.tdm	4,253	1	3,267	23,186	1	0,750	1	0,734
4	Button_1_b.tdm	4,258	1	3,274	23,101	1	0,745	1	0,698
4	Button_1_c.tdm	4,246	1	3,293	22,435	1	0,761	1	0,731
4	Button_1_d.tdm	4,248	1	3,221	24,191	1	0,747	1	0,726
4	Button_1_e.tdm	4,261	1	3,188	25,192	1	0,749	1	0,730
4	Button_1_f.tdm	4,254	1	3,261	23,350	1	0,751	1	0,730
4	Button_1_g.tdm	4,255	1	3,272	23,088	1	0,743	1	0,709
4	Button_1_h.tdm	4,275	1	3,274	23,423	1	0,760	1	0,736
4	Button_1_i.tdm	4,262	1	3,288	22,866	1	0,740	1	0,720
4	Button_1_j.tdm	4,279	1	3,250	24,043	1	0,760	1	0,736
4	Button_1_k.tdm	4,265	1	3,290	22,854	1	0,761	1	0,735
4	Button_1_l.tdm	4,283	1	3,241	24,326	1	0,727	1	0,706
4	Button_1_m.tdm	4,268	1	3,335	21,866	1	0,766	1	0,734
4	Button_1_n.tdm	4,270	1	3,312	22,430	1	0,765	1	0,735
4	Button_1_o.tdm	4,289	1	3,314	22,740	1	0,749	1	0,712
4	Button_1_p.tdm	4,266	1	3,313	22,343	1	0,764	1	0,743
4	Button_1_q.tdm	4,280	1	3,336	22,065	1	0,756	1	0,729
4	Button_1_r.tdm	4,270	1	3,348	21,602	1	0,763	1	0,734
4	Button_1_s.tdm	4,272	1	3,398	20,457	1	0,763	1	0,718
4	Button_1_t.tdm	4,284	1	3,258	23,949	1	0,738	1	0,717
4	Button_1_u.tdm	4,283	1	3,246	24,217	1	0,733	1	0,707
4	Button_1_v.tdm	4,295	1	3,285	23,522	1	0,752	1	0,725
4	Button_1_w.tdm	4,279	1	3,332	22,127	1	0,742	1	0,706
4	Button_1_x.tdm	4,283	1	3,324	22,375	1	0,767	1	0,734
4	Button_1_y.tdm	4,293	1	3,338	22,249	1	0,768	1	0,740
4	Button_1_z.tdm	4,289	1	3,367	21,493	1	0,756	1	0,714
11	Button_2_a1.tdm	4,763	1	3,754	21,171	1	0,744	1	0,716
11	Button_2_b.tdm	4,819	1	3,734	22,515	1	0,743	1	0,716
11	Button_2_c.tdm	4,800	1	3,676	23,427	1	0,717	1	0,699
11	Button_2_d.tdm	4,790	1	3,684	23,103	1	0,732	1	0,714
11	Button_2_e.tdm	4,774	1	3,727	21,929	1	0,740	1	0,710
11	Button_2_f.tdm	4,786	1	3,708	22,534	1	0,746	1	0,727
11	Button_2_g.tdm	4,778	1	3,704	22,488	1	0,749	1	0,718
11	Button_2_h.tdm	4,778	1	3,693	22,713	1	0,750	1	0,720
11	Button_2_i.tdm	4,806	1	3,732	22,350	1	0,754	1	0,727
11	Button_2_j.tdm	4,769	1	3,715	22,097	1	0,743	1	0,716
11	Button_2_k.tdm	4,786	1	3,690	22,905	1	0,745	1	0,717
11	Button_2_l.tdm	4,769	1	3,748	21,408	1	0,747	1	0,716
11	Button_2_m.tdm	4,759	1	3,686	22,544	1	0,735	1	0,711
11	Button_2_n.tdm	4,776	1	3,729	21,931	1	0,754	1	0,733
11	Button_2_o.tdm	4,768	1	3,712	22,159	1	0,736	1	0,710
11	Button_2_p.tdm	4,790	1	3,721	22,325	1	0,745	1	0,717
11	Button_2_q.tdm	4,773	1	3,673	23,049	1	0,736	1	0,721
11	Button_2_r.tdm	4,770	1	3,724	21,925	1	0,761	1	0,725
11	Button_2_s.tdm	4,753	1	3,677	22,637	1	0,733	1	0,712
11	Button_2_t.tdm	4,759	1	3,770	20,776	1	0,744	1	0,710
11	Button_2_u.tdm	4,761	1	3,706	22,151	1	0,754	1	0,730
11	Button_2_v.tdm	4,761	1	3,744	21,352	1	0,755	1	0,720
11	Button_2_w.tdm	4,762	1	3,716	21,969	1	0,743	1	0,716
11	Button_2_x.tdm	4,760	1	3,750	21,211	1	0,738	1	0,712
11	Button_2_y.tdm	4,775	1	3,665	23,232	1	0,737	1	0,719
11	Button_2_z.tdm	4,781	1	3,722	22,149	1	0,757	1	0,735
13	Button_3_a.tdm	3,906	0	2,975	23,828	1	0,767	1	0,711
13	Button_3_b.tdm	3,893	0	2,965	23,842	1	0,763	1	0,730
13	Button_3_c.tdm	3,867	0	2,999	22,448	1	0,752	1	0,725
13	Button_3_d.tdm	3,872	0	2,994	22,683	1	0,783	1	0,742
13	Button_3_e.tdm	3,839	0	2,938	23,471	1	0,777	1	0,752
13	Button_3_f.tdm	3,820	0	2,937	23,107	1	0,764	1	0,730
13	Button_3_g.tdm	3,823	0	2,938	23,150	1	0,758	1	0,719
13	Button_3_h.tdm	3,829	0	2,914	23,911	1	0,753	1	0,722
13	Button_3_i.tdm	3,834	0	2,916	23,942	1	0,757	1	0,710
13	Button_3_j.tdm	3,845	0	2,948	23,311	1	0,780	1	0,737
13	Button_3_k.tdm	3,841	0	2,890	24,759	1	0,758	1	0,717
13	Button_3_l.tdm	3,826	0	2,876	24,815	1	0,750	1	0,726
13	Button_3_m.tdm	3,838	0	2,916	24,017	1	0,738	1	0,698
13	Button_3_n.tdm	3,844	0	2,896	24,664	1	0,725	1	0,704
13	Button_3_o.tdm	3,828	0	2,866	25,138	1	0,747	1	0,701
13	Button_3_p.tdm	3,826	0	2,906	24,042	1	0,757	1	0,724
13	Button_3_q.tdm	3,809	0	2,939	22,844	1	0,755	1	0,723
13	Button_3_r.tdm	3,804	0	2,854	24,978	1	0,753	1	0,724
13	Button_3_s.tdm	3,826	0	2,920	23,675	1	0,755	1	0,722
13	Button_3_t.tdm	3,828	0	2,932	23,393	1	0,770	1	0,734
13	Button_3_u.tdm	3,817	0	2,894	24,179	1	0,753	1	0,716
13	Button_3_v.tdm	3,816	0	2,910	23,745	1	0,742	1	0,716
13	Button_3_w.tdm	3,800	0	2,885	24,079	1	0,751	1	0,718
13	Button_3_x.tdm	3,801	0	2,941	22,611	1	0,751	1	0,713
13	Button_3_y.tdm	3,808	0	2,904	23,744	1	0,767	1	0,715
13	Button_3_z.tdm	3,816	0	2,938	23,002	1	0,764	1	0,729

Accuracy test

Button	Button repetition	F1 [N]	Operating Force?	F2 [N]	SNAP [%]	SNAP?	S2 [mm]	Stroke at min force?	S1 [mm]
1	Button_1_a.tdm	3,926	0	2,803	28,602	1	0,841	0	0,823
	Button_1_b.tdm	4,258	1	3,274	23,101	1	0,745	0	0,698
	Button_1_c.tdm	3,913	0	2,773	29,137	1	0,834	0	0,810
2	Button_2_a.tdm	4,508	0	3,324	26,264	1	1,073	0	1,048
	Button_2_b.tdm	4,438	1	3,268	26,364	1	1,071	0	1,048
	Button_2_c.tdm	4,450	1	3,270	26,514	1	1,068	0	1,042
3	Button_3_a.tdm	3,976	0	3,022	23,989	1	0,938	0	0,918
	Button_3_b.tdm	3,968	0	3,042	23,329	1	0,939	0	0,914
	Button_3_c.tdm	3,960	0	2,975	24,866	1	0,933	0	0,904
4	Button_4_a.tdm	4,317	1	3,220	25,414	1	0,749	1	0,704
	Button_4_b.tdm	4,280	1	3,232	24,481	1	0,752	1	0,730
	Button_4_c.tdm	4,262	1	3,312	22,278	1	0,757	1	0,712
5	Button_5_a.tdm	4,376	1	3,376	22,853	1	0,981	0	0,954
	Button_5_b.tdm	4,332	1	3,257	24,807	1	0,950	0	0,933
	Button_5_c.tdm	4,312	1	3,247	24,696	1	0,976	0	0,950
6	Button_6_a.tdm	4,362	1	3,185	26,974	1	1,073	0	1,046
	Button_6_b.tdm	4,320	1	3,169	26,637	1	1,055	0	1,027
	Button_6_c.tdm	4,291	1	3,176	25,990	1	1,053	0	1,032
7	Button_7_a.tdm	4,262	1	3,339	21,659	1	0,911	0	0,888
	Button_7_b.tdm	4,241	1	3,335	21,357	1	0,885	0	0,861
	Button_7_c.tdm	4,223	1	3,355	20,557	1	0,912	0	0,875
8	Button_8_a.tdm	4,610	1	3,579	22,356	1	0,694	1	0,674
	Button_8_b.tdm	4,565	1	3,602	21,089	1	0,692	1	0,667
	Button_8_c.tdm	4,569	1	3,607	21,048	1	0,698	1	0,677
9	Button_9_a.tdm	4,714	1	3,727	20,941	1	0,842	0	0,814
	Button_9_b.tdm	4,661	1	3,644	21,823	1	0,814	0	0,788
	Button_9_c.tdm	4,649	1	3,683	20,783	1	0,840	0	0,809
10	Button_10_a.tdm	4,449	1	3,514	21,007	1	0,803	0	0,778
	Button_10_b.tdm	4,345	1	3,442	20,774	1	0,830	0	0,795
	Button_10_d.tdm	4,327	1	3,427	20,801	1	0,824	0	0,798
11	Button_11_a.tdm	4,888	1	3,786	22,546	1	0,740	1	0,707
	Button_11_b.tdm	4,816	1	3,709	22,976	1	0,732	1	0,705
	Button_11_c.tdm	4,803	1	3,750	21,940	1	0,747	1	0,712
12	Button_12_a.tdm	4,107	1	3,197	22,151	1	0,841	0	0,804
	Button_12_b.tdm	4,075	1	3,135	23,069	1	0,842	0	0,820
	Button_12_c.tdm	4,074	1	3,151	22,654	1	0,833	0	0,800
13	Button_13_a.tdm	4,063	1	3,055	24,819	1	0,795	1	0,765
	Button_13_b.tdm	3,919	0	3,040	22,428	1	0,780	1	0,754
	Button_13_c.tdm	3,902	0	3,016	22,700	1	0,767	1	0,727
14	Button_14_a.tdm	4,139	1	3,207	22,501	1	0,841	0	0,806
	Button_14_b.tdm	4,104	1	3,227	21,365	1	0,834	0	0,792
	Button_14_c.tdm	4,077	1	3,186	21,845	1	0,822	0	0,790
15	Button_15_a.tdm	4,437	1	3,461	22,003	1	0,797	1	0,764
	Button_15_b.tdm	4,423	1	3,413	22,844	1	0,789	1	0,761
	Button_15_c.tdm	4,398	1	3,434	21,924	1	0,805	0	0,774
16	Button_16_a.tdm	7,750	1	5,622	27,454	1	0,668	1	0,645
	Button_16_b.tdm	7,709	1	5,524	28,347	1	0,651	1	0,618
	Button_16_c.tdm	7,797	1	5,483	29,680	1	0,649	1	0,609
17	Button_17_a.tdm	7,468	1	4,796	35,784	0	0,669	1	0,627
	Button_17_b.tdm	7,487	1	4,966	33,662	1	0,632	1	0,604
	Button_17_c.tdm	7,472	1	4,923	34,121	1	0,634	1	0,590
18	Button_18_a.tdm	4,941	1	3,518	28,806	1	0,859	0	0,828
	Button_18_b.tdm	4,960	1	3,613	27,165	1	0,839	0	0,787
	Button_18_a.tdm	4,931	1	3,510	28,821	1	0,819	0	0,769