Design of a gear shifting system for bicycles.

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Abstract

This project presents the redesign process of a gear shifting mechanism, which is used, in the transmission of bicycles, to activate different speeds.

1. Introduction

Throughout history, the bicycle has changed several times implementing various functional, comforting, safety and even efficiency innovations, such as the gear shifting system. This system is incorporated in the transmission assembly to transform the energy provided by the traveler into speed or torque, depending on the features of the journey.

The main goal of this project is to carry out the design process of a proposal focused on a gearing mechanism. Since the proposed design is not defined previously, research on state of the art of these mechanisms and the proposal selection precede the design process.

Regarding the design developed, the main goals stablished for the proposal are as following:

- The value proposition must focus on functional improvement with respect to the precedents or references studied.
- The integration of the different ideas studied during the previous research phase.

As for the methodology, aside the research and proposal selection, the process includes the analysis of static and dynamic performance of the parts, finite elements and kinematic simulations and the definition of the materials used, all together with the proper decisions for the mechanism to work correctly.

2. State of the art

The gear mechanism is used in different forms for all types of vehicles. The manual transmission gearbox is commonly used for combustion vehicles, such as cars and trucks. In the case of motorcycles, the manual transmission also incorporates a sequential ratchet mechanism, which is more comfortable and faster to use.

Regarding the bicycles, the most common mechanism is the external chain transmission, which also includes a derailleur shifting system.

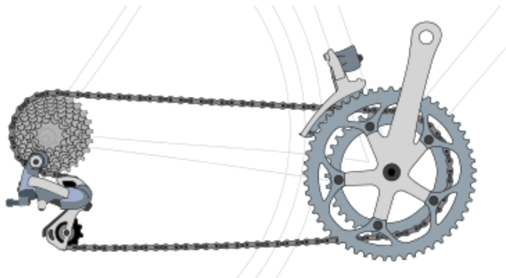

Figure 1. External derailleur system.

However, parallelly to the development of the derailleur, an internal mechanism also started to be commercialized. The internal gearing hub displaces the gearbox to the insides of the hub of the rear wheel, giving a more comfortable and safety system with none moving parts outside the assembly.

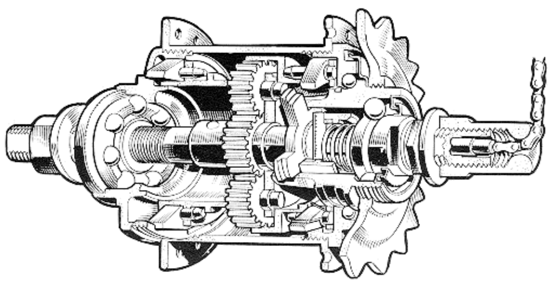

Figure 2. Internal gearing hub.

Both systems were very popular during the last centuries and were developed in order to reach better features and to adapt to the modern bicycles.

3. Proposal selection

From the information obtained during the research some ideas raised as possible proposals to be used. In general terms, the internal hub is considered more interesting, in particular the 3-speed Sturmey Archer, which is one of the first models commercialized successfully.

Leaving aside the different proposals, which have been finally rejected due to the lack of viability, the idea selected focuses on the redesign of the speed selection system.

The Sturmey Archer model utilizes a cable and a compression spring, to control the position of the clutch part of the gearing hub. This clutch consists in a star-shaped part which moves axially along 3 positions in order to engage the required speeds.

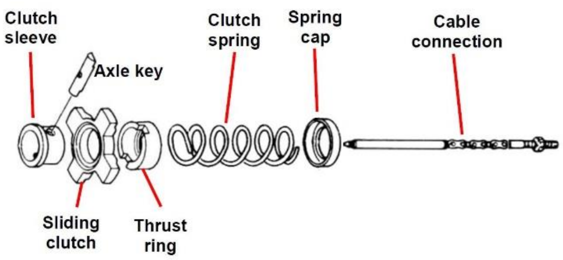

Figure 3. Parts of the speed selection system.

Due to the constant and frequent use of the selection mechanism, the cable might present a lack of tension and generate errors in the selected speed.

The proposed solution consists in the incorporation of a ratchet drum system, which is also used by motorcycle sequential gearboxes.

This system incorporates a selector drum which rotates by the contact of a pawl part. This works as a moving pawl, which engages and pulls the drum, and is activated by the tensioning cables connected in both directions. The drum rotates while transmitting the movement to the rest of the mechanism and displacing the set of clutch parts.

In practice, the transmission from drum to the clutch parts, require a specific mechanism. First, the typical crank-rod-piston assembly was considered. This allows to transform the rotation of the crank to the sliding movement of the piston.

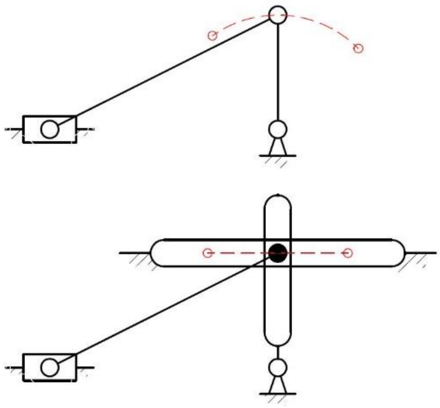

Figure 4. Crank-rod-piston mechanism and modification.

Nevertheless, this mechanism presents some limitations for the ratchet drive system. Since the three positions of the clutch are equally spaced, the trajectory described by the crank drum can not be drawn symmetrically about the vertical axis. This means that the drum must rotate in different angles from the second speed, in order to activate the first and the third ones.

This asymmetry causes the design of the ratchet drive assembly to be much more complex, and unviable. However, replacing the rotating joint, which connects the crank to the rod, by a horizontally guided pin, is a suitable alternative for the drum to rotate in a symmetric trajectory.

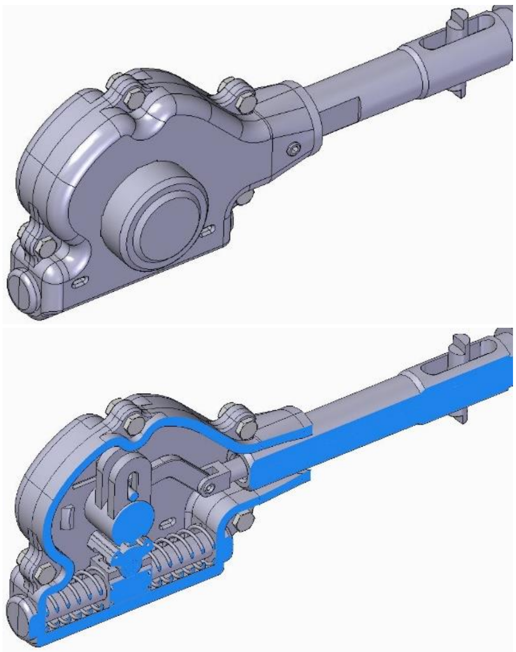

Figure 5. Results of the design process.

Considering the main subject, the solution adopted by this proposal is focused on avoiding the constant stretch of the driving cable. The ratchet mechanism is connected to the selector system during the contact instant, activating the pertinent speed, and returns to the initial position when the operation finishes. Since the cable is only stretched during this operation, the continuous effort is eliminated.

Finally, the proposal is developed by the design process, which is explained in detail below.

4. Mechanical design

The design process is based on the following steps:

- Calculation of free body diagrams and the loads applied to every piece of the mechanism.
- Definition of strain diagrams and the most loaded sections of the part.
- Calculation of the maximum stresses produced in the critical points of the section, and the Von Mises stress.
- Comparison of static stresses and the yield strength of the material.
- Calculation of the dynamic loads produced in the critical points of the part.
- Calculation of the fatigue strength.
- Definition of the Goodman diagram and validation of the fatigue performance of the part.
- Finite elements simulations for every part and comparison to the theorical calculations.

For every phase of the process, in case of not reaching an adequate safety factor, the required modifications will be taken, such as the change of the material used or the dimensional modification of the part.

According to the mechanism used, the design is formed by 6 parts in total. Considering the sliding joints, articulations, and cams, which have one degree of freedom, and the guiding joints, which have two, the global degrees of freedom results to be one. This means that the mechanism just needs one driving element to control its position. As explained above, this element is the pawl part, which is driven by the cable.

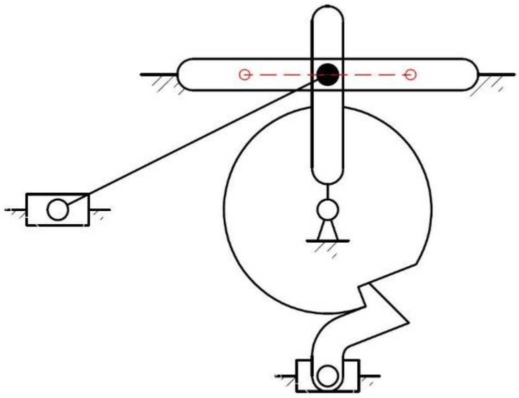

Figure 6. Schematic drawing of the global mechanism.

As initial conditions for the process, the material of use for the elements of the mechanism has been selected. Given the great mechanical capacity and variety of steel materials, the design will use AISI 1006 with 165 MPa yield strength and 295 MPa ultimate strength.

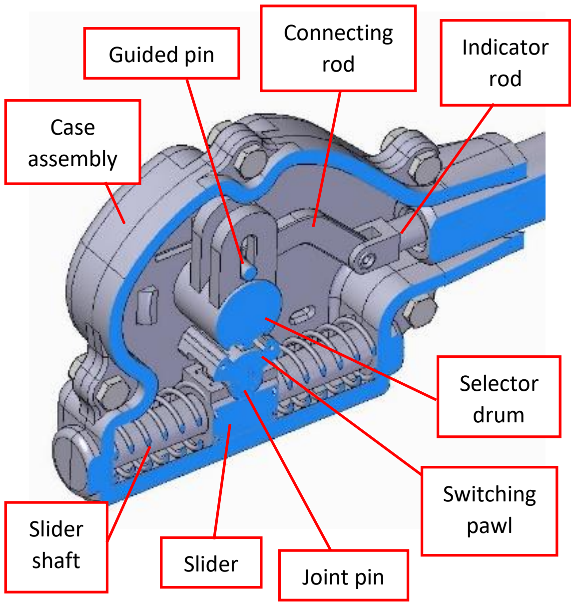

Figure 7. Parts of the final ratchet shifting product.

From a first model of the assembly, the general dimensions of the parts have been determined. The reactions transmitted along the mechanism have also been calculated using the equilibrium equations, and the free body diagrams of each piece.

Considering a minimum 1,4 safety factor, the most compromised parts and the decisions taken to adapt them are the following:

- The stress concentration generated in the articulated joint of the switching mechanism compromises the static work of the part. An increase in the external diameter of the joint allows the safety factor to be reach 1,4.

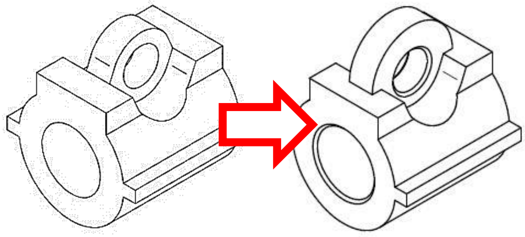

Figure 8. Dimensional modification of the slider articulation.

- Both the selector drum and the connecting rod, as well as the guided pin that joins them, work correctly with safety factors higher than 1.8. This assembly is responsible for transforming the rotary movement into an axial displacement of the clutch assembly.

- Bearings with a 6 mm internal diameter, mounted in the selector drum, are not compromised by the forces applied by this part. The expected lifetime for these allows not to consider their dynamic failure at any time.

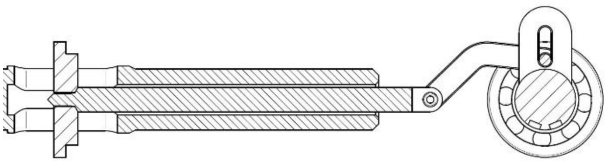

Figure 9. Final design of the clutch-selector mechanism.

- The indicator rod, which connects the assembly with the internal mechanism of the gearing hub, is the most strained part of the set. Both the calculations and the simulations show that the part exceeds the yield strength of the material. As the dimensions of the part are limited by the shaft design, a new material has been selected. AISI 51B60H tempered steel has a 1500 Mpa yield strength and a 1680 Mpa ultimate strength, obtaining the 1,4 safety factor.

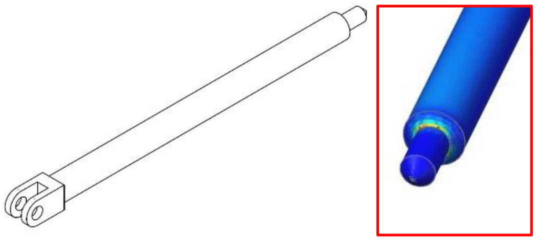

Figure 10. Final design of the indicator rod.

- Regarding the set of cases that holds the mechanism, these are designed to be assembled by bolts and nuts, mounted in 4 points. Also, by means of a set of studs, these parts are fixed to the axle of the gearing hub. The calculations establish that to avoid the failure of the stud bolts and to keep the assembly position of the bolts, the mounting force cannot exceed 2000 N. In the simulation, the case parts are only able to withstand a maximum 950 N load for the mounting of the studs, while the bolt can be mounted by the 700 N load.

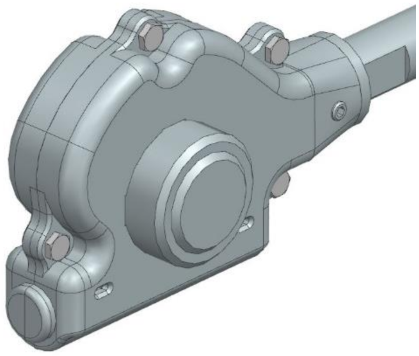

Figure 11. 3D model of the case assembly.

- To conclude, a kinematic simulation has been carried out to check the movements made by the different mechanisms of the set. In these it is verified that the ratchet drive system requires a 4,6 mm displacement on the slide to generate the 45º rotation of the drum. The selector mechanism translates this angular movement into the axial displacement of the internal hub clutch. The simulation also verifies that the final displacement of the clutch is 6.5 mm for each 45º of the drum, values expected and required for the operation of the ratchet shifting system.

5. Budget

The engineering budget considers the value of the tasks accomplished by the professional engineer along the project. Assuming the remuneration of the engineer is 30 euros per hour, the 626 hours of work equate to 18780 € total budget.

The material budget includes the standardized components, obtained by the suppliers, and the parts designed during the project. For the designed ones, the costs consider the material used and the production process.

ENGINEERING BUDGET	18.780,00 €
MATERIAL BUDGET	24,19 €
PRICE	48,38 €
AMORTIZATION EXCESS	24,19 €

Table 1. Summary of budget and amortization.

The final manufacturing cost of the product results to be 24,19 €. Assuming a 200% price, the profit obtained by each product is 24,19 €, which must be used to amortize the engineering budget. A total 777 ratchet shifting systems must be sold to amortize this project.

6. Conclusions

The project has been divided in different phases: research, definition of the proposal and mechanical design. These have been completed successfully, obtaining satisfactory results.

Regarding the proposal, the ratchet shifting system is considered an interesting solution for the troubleshooting of the original Sturmey Archer product.

However, some aspects of this design might be modified in order to describe a more complete proposal.

- The dimensions of the parts are minimum, which might originate problems in the manufacturing and mounting processes.
- On the other hand, the calculation of free body diagrams might not be totally accurate. A complementary dynamic simulation would be able to define the applied loads better.

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