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A new concept of automated manufacturing process for wire rope terminals

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Abstract

The products related to automotive industry need to be extremely competitive. The metallic wire ropes used to open doors in the vehicles are based on a braided wire rope provided with accessories. The more expensive is the vehicle, the more complex is the required final wire rope. In order to prevent the corrosion and reduce noise, the internal metallic cable can be coated with a polymer via extrusion. However, this coating needs to be removed from the extremities of the metallic cable, allowing the zamak injection of the mechanical terminals, preventing die casting defects. Nevertheless, the standard machines able to produce the mechanical terminals by die casting process were always prepared to work only with non-coated metallic cable. Customers demanding coated metallic cables impose the need to adapt the standard machines to this new reality. Thus, new systems needed to be added to the standard machine, allowing the metallic cable strip operation. Moreover, this operation needs to be added to the process but without repercussions on the cycle time. Different approaches were studied and tested in order to find the best solution. The new device was designed and produced, allowing its test in real conditions. The system based on just one blade did not show satisfactory results, being necessary the use of a system based on multiple blades. The new device, when connected to the standard machine, allows to produce wire ropes up to 2.5 meters long, striped in both sides, letting the die casting injection of the zamak terminal in one extremity, with a cycle time of 7 seconds (1000 wire ropes per hour, as they are produced in couples).

Keywords: Wire Rope; Bowden Cables; Coated Wire; Automation; Zamak; Injection Machine.

1. Introduction

Metallic wire ropes have been widely used as structural elements due to their high axial strength and bending flexibility, as well as fatigue resistance, light weight, stability and reliability under dynamic load. They are widely used in cranes, elevator lifting, suspension bridges, aerial rope ways and automotive industry [1, 2]. They can be constructed from either a single straight strand or from several strands that are wound around a core [3]. As it is a bearing component, wire rope can be exposed to fatigue, corrosion, and even a sudden break. The bending, tensile stress and contact with other elements are some reasons for deterioration of wire rope over time [4]. Monitoring and controlling their integrity is a major concern for manufacturers, users, owners and safety authorities, especially when used in automotive industry. With the aim of achieving the new goals imposed, leading the automotive industry to the cutting edge of the development, the efforts in technological improvements and the development of new materials and processes to minimize wear are nowadays one of the highest concerns to engineering [5]. Steel cables, as stated before, are widely used in various fields of engineering and industry. In the automotive industry, they are rarely used on their own, they are commonly used as a part of a more complex system: mechanical control cables or Bowden cables [6-8]. These assemblies can be complex, depending on the function or the system requirements, being constituted of a core wire, end fittings and a conduit [9,10]. Each part plays a different function: the core wire transmits the movement from one end to the other by means of the end fittings, and the conduit acts as

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a guide for the core, also as a support for grommets, spring or other fittings [11]. Focusing on the core wire, since it is the main source of movement, different types of construction and materials must be taken into account, depending on the required function. Thus, in terms of construction, there are two categories: single strand and multi-strand core construction [11, 12]. Single strand consists of a steel wire braced in a certain angle, which are designated for the number of "filaments" constituting the wire, i.e., 1x12 means that the wire is single strand with 12 wires [13]. In terms of material, the manufacturers also must select the material of the wire core, depending mainly on the required corrosion resistance. Usually, wire ropes are made of stainless steel and galvanized steel, however, in order to improve the corrosion resistance, reduce the noise and enhance the efficiency (e.g. reducing the friction between the cable and the remaining components), the inner metallic cable can be coated with a polymer using an extrusion process. Materials commonly available for coating are Polyethylene, PVC, PMMA and PTFE [14], however, this coating needs to be removed from the extremities of the metallic cable, allowing the zamak injection of the mechanical terminals, preventing die casting defects. Also, as part of the process, the cable needs to be hammered, deforming the extremity, thus increasing the tensile strength of the injected part and, as previous experiments have shown, the best result in term of tensile strength are obtained with stripped wire. In the automotive industry, these new challenges in production systems appear on a regular basis, due to the increase of new models and products, therefore automation is widely used to surpass these difficulties. Consequently, countless studies have been made with the main objective of upgrading production systems, thus, decreasing waste and increasing productivity.[15-20]. Integrating operations in the same equipment is an effective way to maintain a continuous work flow. Furthermore, reducing intermediate stocks and logistics, reduces the cost per part, thus increasing profit [15, 20-22]. Also logistics cost takes an important role in general production charges, furthermore they have become a crucial factor due to the increasing range of products manufactured and the need for rapid response imposed by the market [23]. This work was developed aiming the integration of a new device into an existing machine able to remove the plastic coating on the tips of metallic cables, allowing the high-pressure die casting of mechanical end fittings in zamak alloy in a continuous and automatic way. The novel equipment allows the automatic metallic cable strip operation. Moreover, this operation was added to the process without interfering with the initial cycle time. This system represents a real novelty in this kind of equipment and process.

2. Methodology

2.1. Background

The main goal of this work was developing and integrating in an existing high-pressure die casting machine an automatic stripping operation, allowing for the injection of small parts (end fittings) on coated wire ropes, Fig. 1. These products are used in automotive industry for mechanical actuation of devices, such as to open doors, fuel tank flaps, and so on. The covered wire ropes need to be stripped on both tips, in order to inject the end fitting, as shown in Fig. 2, where the side A corresponds to the end fitting and the side B represents the stripped wire rope.

Fig. 1. Finished product – wire rope with end fitting.

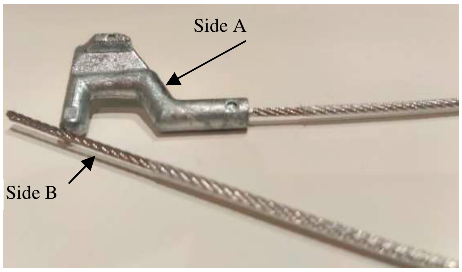

Fig. 2. Detail of the finished product.

The cable, as explained before, is subjected to tensile load, being the end fittings crimped or injected (in this case injected by die casting), responsible for the connection to the devices. End fittings are the link between the cable and the mechanism that will be trigged, so manufacturers expect the connection between the injected part and the wire to be as strong as possible. Even though it is possible to hammer the cable without stripping, the force beard by the injected part decreases if the cables are not free of coating. The main cause is that the coating acts like a barrier between the zamak and the wire, thus preventing infiltration on the structured wire. The coating also prevents the ability to form a wider flower shape (designation of the format obtained after hammering the cable). In Fig. 3, picture A is a cable hammered with coating and B a stripped cable also hammered, and the differences are visible in size and in shape. Picture B presents a flatter flower shape and it is possible to see the spaces between the wires for zamak to infiltrate and produce a stronger linkage between the end fitting and the wire. In comparison, A is smaller and rounder, and with no spaces since they are blocked by the polymer coating.

Fig. 3. (a) Hammered Coated and (b) Non-Coated Wires.

Injecting cables is a broadly studied and well-known process to steel cables suppliers and consists of four general steps: cutting the cable by electric or mechanical devices, hammering the cable, injecting the terminal and sprue trimming (Fig. 4Fig.). When using coated steel cable, an extra step needs to be performed between the first and second steps, the stripping operation, which consists of removing the coating and exposing the steel cable, so it can be hammered (Fig. 5).

Fig. 4. General Steps to Obtain Injected Cables

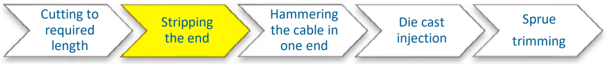

Fig. 5. Steps for Obtaining Injected Cables Using Coated Wire

The process, as stated before, is to be added in a standard fully automated machine that is capable of making the four steps explained before in order to produce injected cables, making cables up to 2500 millimeters in length at a rate of 1000 per hour. The machine is divided in three main assemblies (Fig. 6), an unwinder and compensating unit (1), a cutting system (2) and an injection unit (3). The first system is where the coils of wire rope are placed and fed to the machine, then they pass through the compensator unit where a series of pulleys maintain the cables under tension. After that, the cutting system takes the cables up to the injection unit, where the hammering device (3a) holds it in place, them the cutting system moves back until the required length (the 0 point is the hammering device and the end is the cutting system) and the cables are then cut. The cables are now face to the hammering device where a transfer arm (3d) moves them to the mold (3b) for die casting and cut the sprue in the cutting system (3c), finally a second transfer arm extracts (3e) the cables from the sprue cutting device, holding and pulling them.

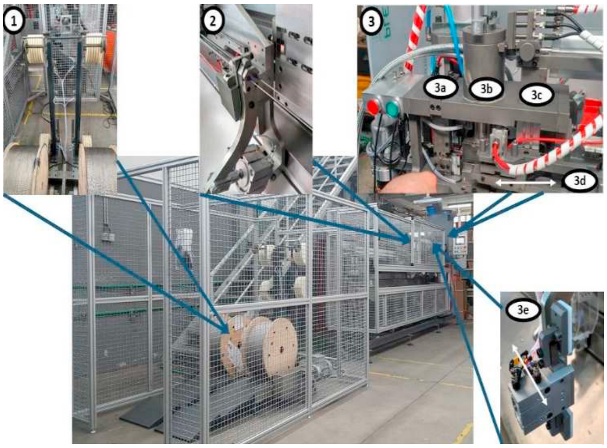

Fig. 6. ZMR Standard Machine.

The main problem, when using coated wire is its inability to use the automatic station, because of the stripping step. Thus, the process is even more inefficient, as it requires three different stations Fig. 7 and, in consequence, three workers. This presents stock and logistics problems as well, even if the three stations are aligned, so the process is extremely inefficient and costly. Another issue in having three separate machines, is that the systems have different rates of production (e.g. the first station produces at a superior rate than the second, unbalancing the line), creating unnecessary stock. Also, with this system a maintenance problem is created. If one of the stations needs intervention, first it is necessary to create a safety-stock and them assure that the intervention is no longer than predicted or it can cause a stop in the production line.

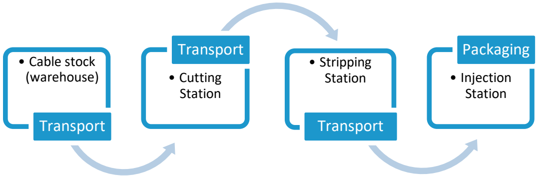

Fig. 7. Steps to Produce Coated Steel Cable.

2.2. Methods

The concept stage consisted of three phases, first the manual system of stripping was studied, because there are some manual systems designed and implement in the market. Thus, the main focus was on the study of the blades and the mechanism itself and on how it could be applied in the already existing equipment concept. All systems have one thing in common: the blade has a special format to allow the coating to be cut and extracted. This was important since one of the customer's requirements was that the machine needs to be able to strip both ends of the cable. Manual or semi-automatic devices consist of two blades with a cutting diameter of the cable plus 0.10 mm, also there are two pneumatic cylinders moving the blades against the cable and one moving the blades back. The main considerations to retain from this system are the blade configuration (Fig. 8) and the load required to cut and pull the coating, the work evolved in making a prototype for testing the blade design to assess if it was possible to use same blade to strip both sides. The second step was to study the ZMR machine cycle, to understand how the stripping operation can be added without affecting the cycle. The next and final step was to redesign the large manual mechanism into a smaller device and adding a second area of stripping since the manual mechanism only was able to produce one cable at time. Thus, for this step four different devices were designed and constructed. The first one was a simple prototype to test the blade design and to predict if one blade was able of stripping both sides, A and B. The second was the first mechanism implemented on the machine, designed by taking into account the results from the prototype. After the first mechanism had been implemented on the machine, the design followed a trial and error method. Thus, the second mechanism was designed and implemented with the lessons learned by the previous one and the third mechanism is a summary of all the results collected from previous tests, achieving the results set in the beginning of this study.

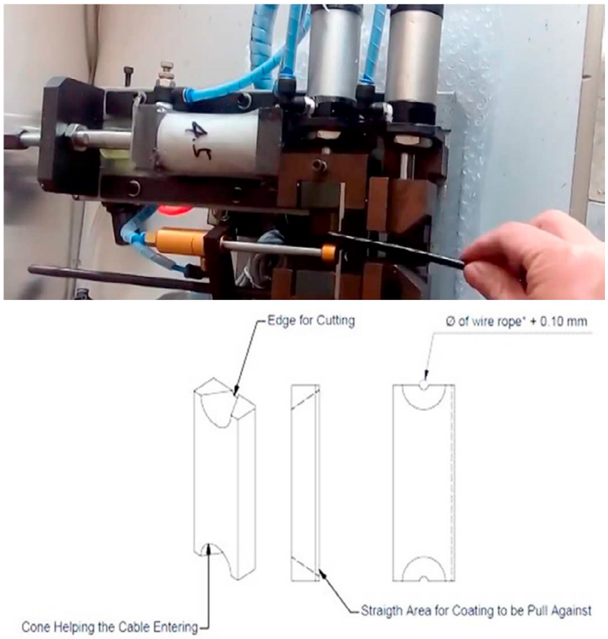

Fig. 8. Manual System and Blade Configuration.

Finally, a savings analysis was performed, i.e., replacing three different stations with one fully automated machine, considering the workforce required to operate the three mechanisms vs workforce required to operate the automatic-line vs equipment cost.

3. Results and Discussion

As explained in the previous chapter, the starting point was a semi-automatic mechanism from which it was made a simple prototype to test the first stage, the blade design. The prototype consisted of a guided cylinder and two blades to test if the same blade was capable to strip both sides. The results showed that if the blade was made using the configuration presented in Fig. 9, it was possible to strip both sides. Another consideration regarding the blade is that besides the straight plane for coating to be pulled against, the blade also has to be sharped for cutting the polymer.

The cycle for stripping was studied and it was decided to use the standard cycle previously mentioned until the cutting system. Then, a pneumatic cylinder introduces the cables for stripping (Fig. 10), and the stripping mechanism is positioned, the blades close and pull the coating. After that, the cables are pushed a second time through the stripping mechanism that holds them and take them to the hammering device (Fig. 11). The hammering device holds them, and the cutting system cuts the desire length. Then, the two mechanisms move back, the stripping device closes and pulls the coating, for stripping side B.

Thus, after the successful test with the prototype, the first mechanism was designed using the premise that one blade is enough to strip both sides and it was implemented in the area after the cutting system. The device consists of two cylinders and two guided parts that housed the blades (Fig. 12). Because the machine needs to be able to produce different cable lengths, two servo-motors were used so that the cutting and stripping mechanisms were able to automatically adjust to the different lengths. The servomotor that is responsible for moving the stripping mechanism also is used as pulling system, thus removing the coating.

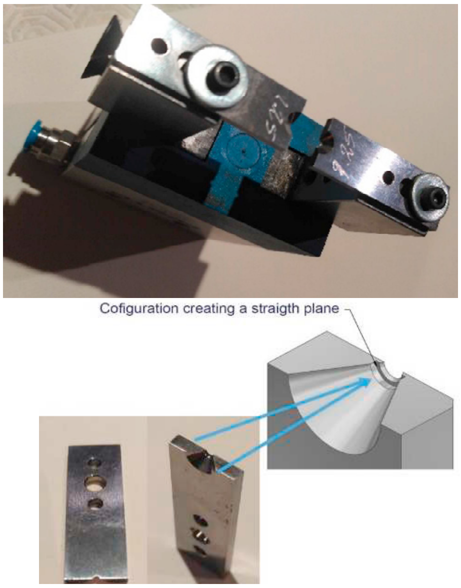

Fig. 9. Prototype and Blade Configuration.

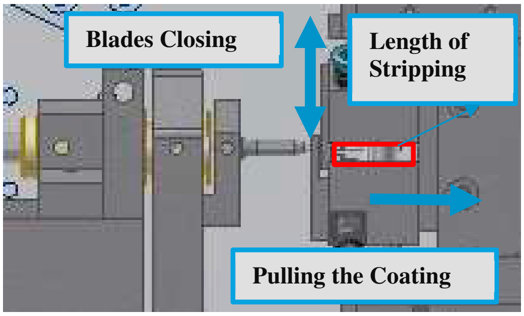

Fig. 10. Position 1 for Stripping.

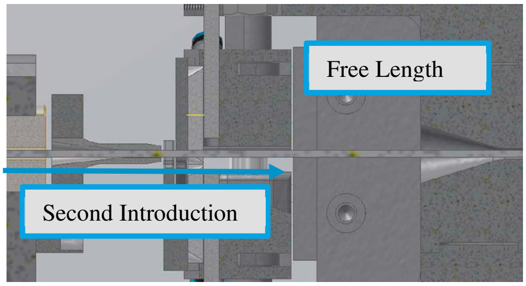

Fig. 11. Position 2 for Delivery in the Hammering Device.

Despite the first promising trials using the prototype, further tests in the current machine did not run as expected, appearing two defects presented in Fig. 13: in picture A the coating is not completely stripped, which was caused by debris that prevented the blades to close completely, displacement between the upper and lower blade, or inability of the mechanism to center the cables in the blades. In Fig. 13B the metallic wire rope is “deinterlaced” because of its fragility when stripped. The main cause was the cables were not entering the tunnel in the second introduction, colliding with a flat area.

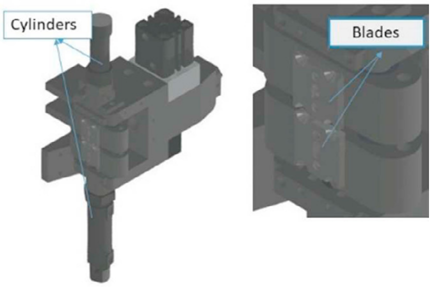

Fig. 12. Defects in the cable tip after the first approach.

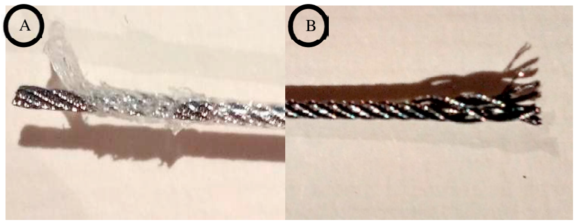

Fig. 13. (a) Stripping Defects and (b) “deinterlaced” Cable.

Thus, this system was reviewed and a series of improvements were implemented to reduce the defects from the first trial (Fig. 14). Regarding the defects in Fig. 14C, four blowers and extractors were implemented to clean the blades after each stripping operation. A recipient was also added for the small ends of polymer to be expelled out, thus preventing the debris from obstructing other mechanisms in the machine. The recipient has a lid to be emptied when full.

The incorrect centering of the cables in the blades was corrected, implementing two metallic parts with a “V” configuration, thus forcing them to the cutting area of the blades. On the other hand, the blade displacement was corrected by adding two centering cones on each side of the blade holders, thus forcing them to close correctly. The incorrect alignment with the tunnel causing the defects is Fig. 14B, was thought to be caused by the previous defects, displacement, incorrect centering and obstruction by debris.

The second mechanism produced better results than the first one, but only on the A side. The B side was still having stripping defects and therefore constant stops. Moreover, problems still persisted with some regularity, the cable not always passed the stripping into the “tunnel”, causing the defect referred before (deinterlaced cable). After establishing that the blade design was not producing the required effects and still having displacement, as well as problems in the introduction in the tunnel, all concept was revised. First, it was decided to implement another blade, with the design consisting of two blades placed back to back, thus allowing for a more effective cutting, as well as a straight plane where the coating can be pulled against. Then, both sides A and B have been correctly stripped.

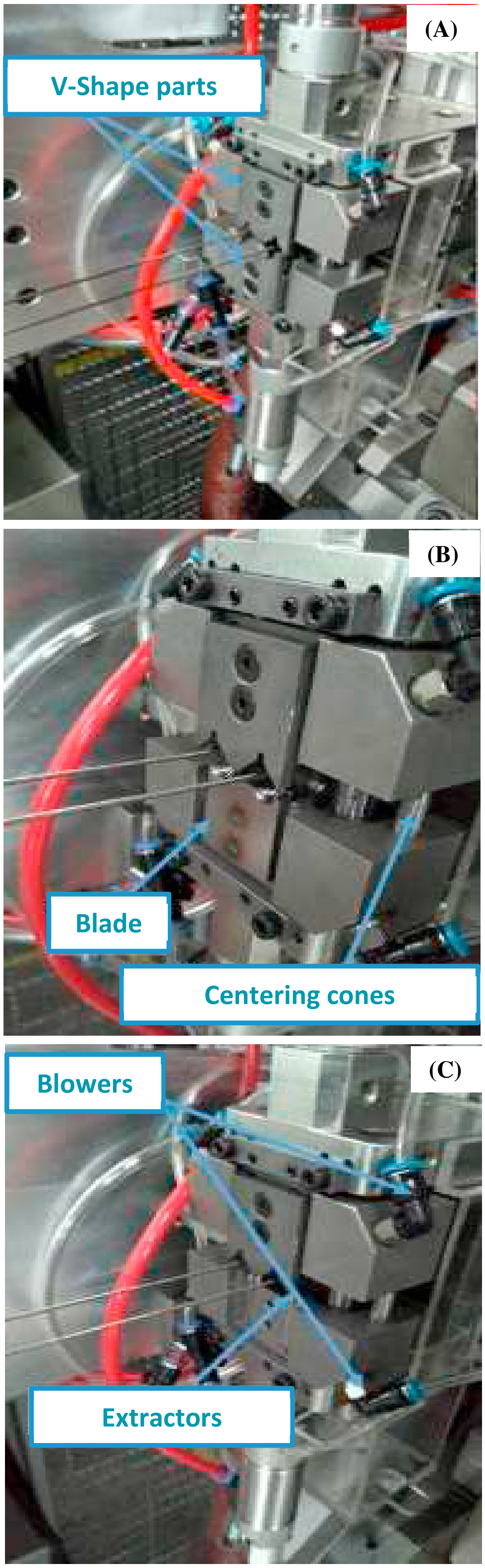

Fig. 14. Single Blade Design with Improvements.

Regarding the displacement problem, it was also reviewed using (a) smaller tolerances in the fabrication, (b) maintaining the two cones on each side of the blades, (c) use of "V" parts previously tested on the mechanism for centering the cables.

Concerning the problem of the free length of the cable which can cause deinterlaced cables, a part in the shape of a tunnel was added, thus guiding the cable and eliminating the problem. This metallic part is usually retracted and is triggered after the stripping operation (Fig. 15). This new design produced the best results in terms of stripping both sides A and B, reducing as well the displacement of the blades. Also the added protection and recipient showed to be efficient on keeping the end coating out of the working area of the machine, reducing the breakdowns due to debris blocking the mechanism.

Summing up, the complete stripping process is as follows:

- The mechanism (cutting + striping) will bring the cables from the unwinder (Fig.15 A).
- Striping of the side A takes place (Fig 15 C), blowers will send a blast of air to clean the stripped polymer.
- Second introduction occurs and holder cylinder holds the now stripped cables in place. The mechanism moves forwards and delivers them to the hammering device (Fig 15D).
- Once secured in the hammering device the mechanism will be positioned to the cable length requirement and blades for side B will close them the cutting occurs.
- The mechanism will move back thus stripping the side B and freeing the cable from the mechanism. The blowers will blast once more to clean any debris left (Similar to the phase 3).

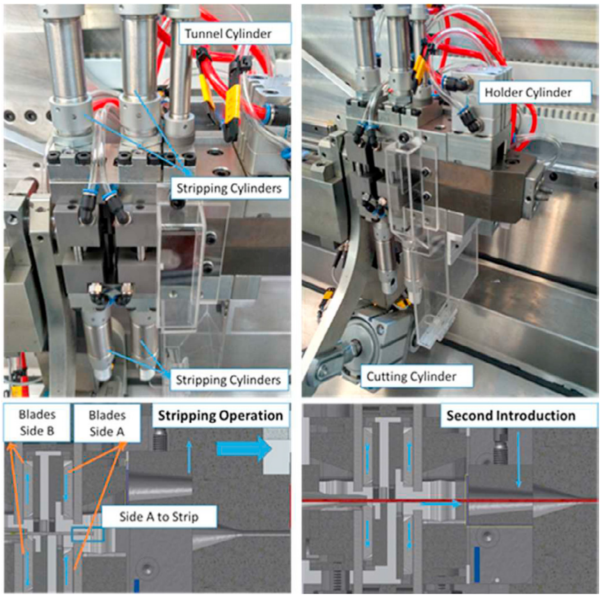

Fig. 15 - Double mechanism: (A) Stripping operation and corresponding cylinders; (B) Cutting operation, with cutting cylinder and corresponding holder cylinder; (C) Blades able to act in the Stripping operation; (D) Mechanism moves forwards and delivers them to the hammering device

The cost estimated for this equipment is 125 000 €, being able of producing coated and non-coated wire rope in a wide range of lengths. However, it must be taken into consideration the two major expenses related to its operation, the cost of paying three workers to operate the different machines and the cost of the injection unit, around 55 000 €. Subtracting this amount to the cost of the new equipment, one can conclude that the estimated pay-back time is 2.3 years, as presented in Table 1.

Table 1. Payback Study

	Manual Operation	**Novel Concept**
Cost per Worker per Year	12,000 €	12,000 €
Number of Workers[1]	3	0,50
Equipment Cost[2]	55 000 €	125 000 €
Operation Cost per Year	36000 €	6,000 €
Investment	--	70 000 €[2]
Saving Per Year	30 000 €	
Pay-Back Time	2,3 Years	

1Considering that it is an automatic machine, it does not need a full-time worker

2 Difference between Novel Concept and Injection Unit (125 000 – 55 000)

4. Conclusions

The aim of this work was to introduce a wire stripping operation onto an existing machine. The main objective was accomplished, mainly through trial and error methodology.

The machine is able to produce cables in different lengths with either coated or non-coated wire ropes, from 350 mm up to 2500 mm, stripping both sides and injecting one of them, using only one operator in half-time, for supplying and controlling the main parameters of the machine.

Using this novel concept, it was possible to transform a semi-automatic operation into a fully automatic machine that receives raw material and delivers a finished product, thus eliminating intermediate stocks and logistics. Also, by integrating all operations in one resulted in an integrated maintenance operation. Furthermore, using a fully automatic machine, it is possible to get a pay-back time of 2.3 years, taking into account only the workforce and initial investment, although this value could be lower if considered the logistics, maintenance and energy expenses.

This work states that through mechanical design and automation it is possible to reduce the labor required to produce automotive parts, thus adding value and reducing time and cost per part.

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