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Designing a Novel System for the Introduction of Lubricant in Control Cables for the Automotive Industry

R. Ribeiro, F. J. G. Silva*, A. G. Pinto, R. D. S. G. Campilho, H. A. Pinto

ISEP – School of Engieering, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal

Abstract

The increasing competitiveness installed in the automotive industry implies continuous improvements in all fields of knowledge and action. Thus, it is very important to be aware of the wastes generate across all the productive and logistics operations. In this regard, and considering the production process of command cables for the automotive industry, it was detected that a significant volume of lubricant is wasted during the task of introducing grease into the spiral used in the command cables utilized to drive the doors, windows and brakes of motor vehicles. The industrial operation was carefully followed leading to identify the main causes of the wastes and a brainstorming was carried out allowing the discussion of new ideas on how to overcome the problem. A novel equipment was developed, being also cared all the logistics around the supplying task. The new solution developed, as well as the redefinition of the logistic process of supplying the lubricating grease to the production lines, made it possible to make the process more flexible for the admission of different grease packs, as well as a better utilization of the existing grease in the reservoirs, resulting in a cut of grease waste by more than 70%. It was also produced a prototype of the grease supply system, which allowed validate the previously developed system.

Keywords: Automotive industry, Command cables, Lubrication, Mechanical design, Environment.

1. Introduction

The automotive industry is a pillar extremely important in the global industrial landscape. According to statistics launched by the OICA - International Organization of Motor Vehicles Manufacturers [1], more than 97 million cars

* Corresponding author. Tel.: +351 228340500; fax: +351 228321159.
E-mail address: fgs@isep.ipp.pt

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were produced worldwide during 2017, representing a growth of 2.36% over the previous year. Due to the competitiveness of this sector of activity, all companies are constantly striving to be able to stand out from the customers for innovation, variety of models and attractive price [2]. In the main assembly lines, robotization has assumed a particular prominence both in sheet metal stamping process and in the vehicles' body welding process [3]. In automotive component manufacturing, reality is no longer linear, with different levels of automation depending on the product, the manufacturer and the country where it is installed [4]. Robotization is typically present in larger components and in countries where labor is more expensive, while manual production is usually related to countries with lower labor costs and low value added products [5]. In any case, there is a growing trend towards the automation of most processes, with a view to quality assurance and increased competitiveness [6]. At the same time, in the more labor intensive industries, significant efforts have been made at management level to reduce cycle times [7], standardize tasks [8, 9], optimize changeovers [10], improve process quality [11] and products [12], thus increasing the competitiveness of this industrial sector. The transition from manual to automated processes has been strongly studied and is one of the main research pillars in the fields of mechanical engineering and industrial control engineering. The work presented here aims to contribute to an extension of the knowledge in the area of the project of equipment capable of increasing the productivity and to assure with greater rigor the quality of the product.

2. Literature review

The automotive component industry has moved among several not-so-easy-to-win challenges: jointly increasing productivity and flexibility, ensuring higher levels of quality [13]. In order to promote the gradual shift from intensive labor-intensive component production to a capital intensive system, some intermediate approaches have been made in the manufacture and assembly of certain components whose manufacture can not be fully automated [14]. The approach to process automation may be carried out as a whole [15] or in a piecemeal fashion. Then a bibliographical review is made on how some researchers promoted the automation of some manufacturing processes. In order to solve the high quality requirements that are required in the fixation of automobile structures during its production process, as well as to reduce the setup time, Fritzsche et al. [16] developed several modules based on artificial intelligence. According to this system, each attachment point is measured and compared to the previously established position in a database. The resulting value of the comparison is introduced in a system that, through a mathematical algorithm based on neural networks, allows the adjustment of position automatically. This ensures the strict positioning required by the production line and customer requirements. Considering the difficulty of manipulating the parts in glass-reinforced plastics, Björnsson [17] made a survey of the literature on the subject, finding that it is a difficult problem to solve, but he listed some ways to solve the problem presented by dimension, geometry and flexibility of these parts. The difference in properties of these materials makes it difficult to automate the process, due to the difficulty in maintaining positional rigidity. In any case, this problem is not limited to glass fiber reinforced plastic parts. The manipulation of bent wires usually used in the metallic structure of seats for car industry presented similar problems, whose have been was recently studied by Magalhães et al. [18]. In this case, the steel wires have different mechanical properties, which provides complete randomness in the direction in which the wire moves when it has just been cut. Given the asymmetry presented by a large part of the forms which these wires must ensure, and the need to put them in a well-known position to be subsequently used by the following process - plastic injection - automatic equipment has been developed to ensure position. Due to the random positioning, it was necessary to use artificial vision to circumvent the problem. The diversity of models has often created serious difficulties for the automation of certain processes carried out essentially at the expense of labor intensive. Nunes and Silva [5] developed an automatic equipment for the assembly of components related to widescreen wipers, in an environment embedded in great diversity of models. This diversity of models is accompanied by a great diversity of shapes, which are difficult to accommodate in a single automatic system. With the aid of automatic vibratory feeders and ingenious positioning and routing systems, it was possible to automate this assembly operation, reducing cycle time by 36% and ensuring much higher quality levels. The labor force allocated to the process was also significantly reduced. A similar study was developed by Costa et al. [19]. A fully automated system was developed, where labor is only necessary for logistics operations to supply components and remove assembled parts. In this case, the body of the pieces was plastic, unlike the case [5], where the bodies of the main pieces were metallic. A completely automated adjustment is possible in [20], so the setup time is insignificant and the quality of the final product is guaranteed. Once again it was used vibrating feeding systems and ingenious guidance and positioning systems, allowing the proper assembly of a varied range of parts belonging to the same family. The cycle time has been shortened and quality control has been ensured through artificial vision. In order to improve quality in the manufacture of components for motor vehicle tires, Santos et al. [20] developed a new concept for one of the stages of tire construction. In this case, an upgrade is designed to improve the process, reduce downtime due to malfunctions, improve operator safety, and shorten setup time. Through a new methodology to approach this multi-variated problem, and with the aid of automation, it was possible to drastically improve the equipment, realizing that all the objectives were achieved. On the other hand, Moreira et al. [21] studied the automation of a process of assembly of drive cables for motor vehicles, normally used for the opening of doors, engine cover, trunk lid, opening and closing of windows, etc. The new concept of assembly equipment of these components for the automotive industry has drastically reduced the workforce allocated to this task, ensuring a higher level of quality and a reduction in setup time and cycle time. At the same time, the equipment has a very high versatility, allowing to handle a vast set of cables of the same family. It should be noted that the equipment allowed to aggregate a set of operations that were carried out in different equipment until then.

The work here presented aims to extend the knowledge about how to automate another task related to the same product, but where it is necessary to integrate grease. This lubricating grease aims to improve the sliding of the metallic cable inside the plastic sheath where it is inserted, as well as to protect the metallic cable against corrosion phenomena. The assembly corresponds to a component called a control cable, which performs the functions previously described in a car. In the literature, no study was found to solve problems of this nature. The development of this work aims at establishing and disseminating some guidelines on how to overcome problems related to this operation, such as: wastage of time, standardization of the task throughout the fleet of machines, facilitate logistical supply operations and avoid wastage of lubricant grease, with the consequent damage to the environment and to the competitiveness of the process.

3. Methodology

Several companies are dedicated to the manufacture of control cables for the most diverse drives in motor vehicles. Fig. 1 shows an example of a control cable. The efficiency of these cables is directly related to the lubrication between the metal cable (1) and its coating. The lubricant minimizes the friction between these two components allowing a quick, smooth and easy movement of the cable, thus conditioning its efficiency. The use of greases in control cables offers several advantages. They can dampen mechanical vibrations and have a greater capacity of permanence in the place, attenuating the problems of leakage associated with the lubricating oils. They also minimize wear through long-term action, which significantly increases the life of the cable. Lubricants with special formulations can provide particularly low coefficients of friction and contain various anti-wear additives, antioxidants and corrosion inhibitors, among others.

The methodology used in this work consisted of the following phases: analysis of the problem, elaboration of the list of requirements and design of an integrated solution that would solve the problem of wasted grease.

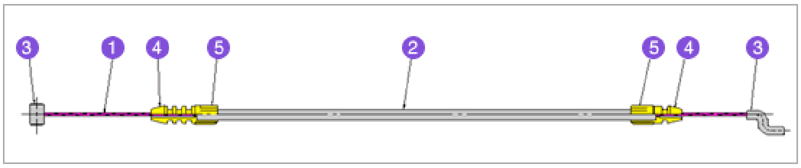

Fig. 1. Example of a simple control cable.
(1) Inner cable, (2) Outer casing, (3) Cable end, (4) Casing cap (5) Clamp.

3.1. Problems Identification

The work has been developed to solve a problem presented by a company that has 38 lines of grease injection in control cables, as shown in Fig. 2. Each of these machines has a grease reservoir, which will be injected into the cable through an injection needle (Fig. 3) and by the action of a pneumatic cylinder. The grease, before being injected into the cable, goes through several steps. The lubricant is supplied to the company in buckets, which can have different dimensions, and are stored in the logistics warehouse. These buckets are then placed in a movable device (Fig. 4) which has to be moved to the injection line to fill the reservoir. In most of the injection lines, the grease supply is performed using this mobile device. However, some injection lines have a fixed device, directly connected to the injection line, which contains the bucket of grease and the components needed to fill the reservoir. The filling of the reservoir is accomplished with this fixed in the line of injection because its removal is something complex and time consuming. In addition, the reservoirs, if not coupled to their injection line, have no device preventing leakage of grease through their outlet port.

This cable lubrication system has several problems. It presents great waste of grease because the equipment used does not allow an efficient extraction of the mass of the bucket. This waste translates into a cost to the company and a loss to the environment. In injection lines with no fixed filling device the operator has to move to the specific place in the production area where the mobile device is located and transport it to the line which needs to fill the reservoir. After filling the reservoir, the operator must return the mobile device to the initial location. This is a time-consuming and difficult task, due to the distances that need to be traveled and the weight of the device itself that has to be moved manually. In addition, it is necessary to connect the reservoir to the mobile device and wait for it to be filled to continue production. This procedure for filling the reservoirs implies, of course, a lower productivity of the injection lines. Another problem is poor lubrication of the cables, due to the introduction of air during the injection of the grease, which can cause a decrease in its efficiency and durability, and may also imply customer complaints.

Fig. 2. Injection line with coupled reservoir.

Fig. 3. Lubricant injection needle.

Fig. 4. Reservoir filling device.

3.2. Requirements for the lubrication system

The lubrication system must fulfill the following requirements:

a. Reduce grease waste through the development of a mechanism that allows total or almost total extraction of the grease from the buckets and also allows the use of buckets of different sizes.
b. Decrease the stopping time of the injection lines for the supply of grease to the reservoirs;
c. Reduce problems caused by poor lubrication of the cables due to the presence of air in the grease when injected into the cable;
d. Minimize the investment needed to implement the aforementioned improvements.

4. Description of the system developed. Results and discussion

In this section, the solutions proposed to improve the lubrication of the control cables and to meet the requirements presented above are presented in a succinct and simplified way.

The work involved a series of steps, covering the whole process of storage, transport and management of grease containers, as well as the adaptation of the reservoirs to the grease filling system into the cables. Moreover, because some air insertion problems were also detected as a problem affecting the quality of the final product, an air detection system was developed that would prevent the injection of air together with the grease.

For the extraction of the mass from the bucket, and consequent filling of the reservoirs, the system shown in Fig. 5 was developed, which should be located in the logistics warehouse. In this solution, where it is possible to supply up to four reservoirs simultaneously, it is the reservoirs that have to be transported to the filling system. The changes introduced into the reservoirs to facilitate their removal and attachment to the injection line, as well as their transport, are presented later. This system has a platform (1) for supporting and fixing the bucket (2), as well as all the components necessary to extract the mass from the bucket and its injection into the reservoirs, previously placed in the filling bench (3). The positioning and fixing of the bucket on the platform is achieved by three claws with concentric movement, and separated from each other by an angle of 120º. The claws are fixed on skids that slide along guides, whose rail size depends on the maximum diameter and minimum diameter of the buckets used in the company. The clutch actuation is performed by a pinion/rack system driven by a pneumatic cylinder. The grease is extracted from the bucket through a hole previously opened in its lower part, and by the action of a metal disc. This disc (Fig. 6), whose diameter depends on the inner diameter of the bucket, has a rubber edge that allows an adequate contact with the side walls of the bucket, in order to minimize the wasted grease, i.e., the mass quantity which remains to be extracted from the bucket. For the vertical movement of the disc, two pneumatic cylinders (4) are used, avoiding the use of a pump, making the solution more economical. At the bottom of the platform, coincident with the bucket hole where the grease is extracted, there is a mechanism (Fig. 7) that promotes the injection of the lubricant into the reservoirs on the filling stand. Fig. 8 shows the lower part of the platform, where the mechanisms of clutch actuation and injection of the grease for the reservoirs are found.

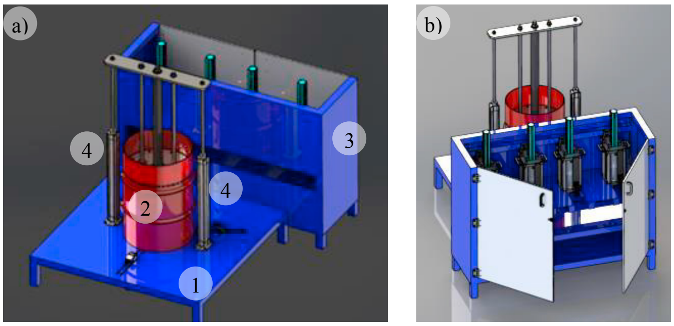

Fig. 5. Reservoir filling system.
a) front view. b) view from behind.
1: platform for bucket support and attachment. 2: bucket.
3: reservoir filling bench. 4: pneumatic cylinders.

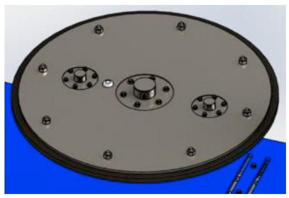

Fig. 6. Metal disc with rubber edge.

In this proposal, as already mentioned, the filling of the reservoirs with grease is carried out in the warehouse and, therefore, it is necessary to contemplate a safe and agile system for their transport and storage.

A suitable solution to transport the reservoirs of the injection lines to the warehouse, and vice versa, is the use of a milk-run (Fig. 9), which usually exists in companies. These milk-run systems, which circulate inside the factory to deliver and collect products, allow to couple several trailers to carry out the respective transport. For the safe transport of the reservoirs, a bench is proposed as shown in Fig. 10, which, in this case, can accommodate three reservoirs. Fig. 11 shows a trailer with a capacity of six benches, i.e., for eighteen reservoirs in total. It should be noted that during a work shift, the mass contained in a reservoir, which maximum capacity is 12 liters, is injected. Thus, the exchange of the reservoirs is only performed at the beginning of each work shift.

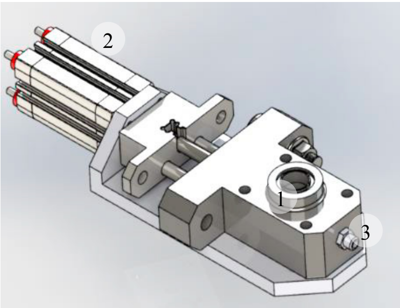

Fig. 7. Injection grease system for reservoirs.
1: hole receiving the mass of lubricant from the bucket.
2: pneumatic cylinder.
3: grease outlet port for the piping connecting this system to the reservoirs.

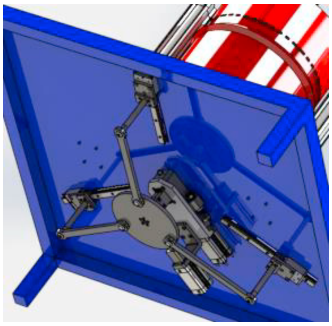

Fig. 8. Bottom of platform supporting bucket.

After the filling of the reservoirs, and for the reception of the empty reservoirs coming from the injection lines, a structure that works as a warehouse is necessary. Fig. 12 shows a bench with three steps on each side that allows to store a total of 48 reservoirs. The height of the steps of this bench must be properly designed so as not to make it difficult to place or remove the reservoirs.

Fig. 9. Milk-run.

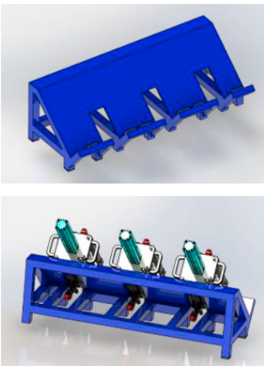

Fig. 10. Reservoir transport bench.

Fig. 11. Trailer transport for treservoirs.

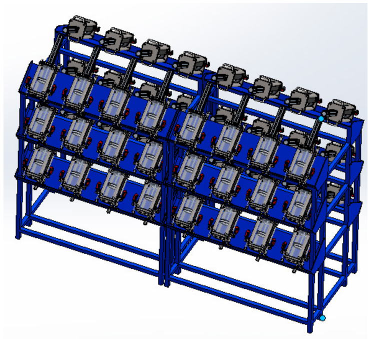

Fig. 12. Bench to store reservoirs.

The system above described allows to reduce wastage of grease, simultaneously supply several reservoirs and store the same reservoirs, empty or already filled with grease. The milk-run collects the empty reservoirs near the injection lines and supplies the reservoir with grease suitable for each line. However, to make this procedure possible, some changes in the reservoirs are required to be transportable and easy to remove and assemble on the injection lines. In addition, reserve reservoirs, previously supplied with grease, are necessary to allow the immediate replacement of the reservoirs that have finished their service (empty reservoir). With this form of actuation, the stopping time of the injection lines for the grease supply is greatly reduced. This is because the filling of the reservoirs is no longer carried out as described previously, and a direct exchange of an empty reservoir by a reservoir previously filled with grease takes place. Furthermore, in the proposed solution, the filling of the reservoirs is no longer carried out with the reservoirs fixed in the injection lines, being performed in the warehouse, where is the filling system shown in Fig. 5. The fixation of the reservoirs, which is performed through bolted connection, is performed with the aid of two clamps and four positioning pins, as shown in Fig. 13 and 14. The holes in the base of the injection line (Fig. 15), for the bolted connection of the reservoirs, are changed to the pin housing. The attachment of the reservoir is now guaranteed by the fixed clamps in the reservoir and the counter clamps fixed at the base of the injection line. This form of fastening allows the quick exchange of reservoirs and their correct positioning in the line of injection.

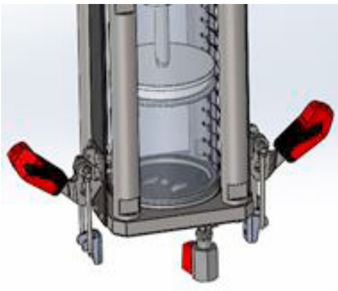

Fig. 13. Reservoir with clamps.

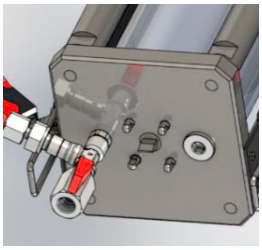

Fig. 14. Positioning pins at the base of the reservoir.

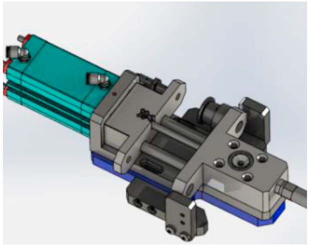

Fig. 15. Injection Line Base.

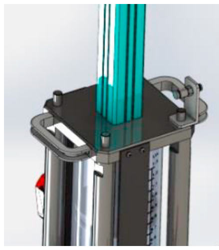

Fig. 16. Reservoir with two handles.

It is also necessary to provide the reservoirs with a mechanism to open and close the hole through which the grease passes to the injection base ie open the hole when the reservoir is placed in the injection line and close when withdrawn from the line of injection. The closure of the hole is necessary to prevent the discharge of grease from the reservoir after filling and during its transport to the injection lines. To achieve this, a mechanism has been developed that allows the opening and automatic closure of this hole. This mechanism basically consists of a stop with a sealing ring and a compression spring. When the reservoir is placed in the injection line, the stopper and the sealing ring are pushed into the reservoir allowing opening of the hole. When the reservoir is withdrawn from the injection base, the spring pushes the stopper out of the reservoir causing the seal to close the hole. This stop can be seen in Fig. 14 and is among the four pins that ensure correct positioning of the reservoir at the base of the injection line. To facilitate the handling of the reservoirs, two handles were placed near the top cover, as shown in Fig. 16. In this upper cover, there is a pneumatic cylinder that promotes the grease output to the base of the injection line. It should be noted that a prototype of this reservoir was manufactured and found to meet the required requirements (ease of disassembly and assembly in the injection line and ease of handling and transport).

In order to detect the presence of air at the time of the grease injection, and to avoid consequent associated problems, a device shown in Fig. 17 was developed, which is basically composed of an adapted pneumatic cylinder (1) and a position sensor (2). The grease, upon entering through the hole in the cylinder cover (3), pushes a shaft which causes the piston to move to a certain position. The sensor must be positioned so that it is aligned with this position. In the injection of only grease, the position of the plunger, for a given cable, is always the same, and will be detected by the sensor. However, if there is air passage, the force exerted on the shaft is smaller and the displacement of the piston will also be less or even zero. In this situation, the sensor does not sense the plunger and should trigger a warning informing the operator that the system contains air, allowing the operation to be interrupted and can be resolved. In this arrangement, the plunger has two grooves for allowing the grease to pass and exit through the component (4), which connects the air detection device and the injection needle. In Fig. 18 and 19, it can be observed the positions of the plunger when there is air in the system, and when only grease is injected.

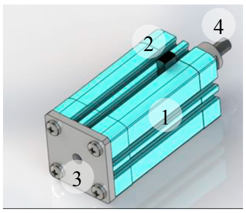

Fig. 17. Air Detection Device.

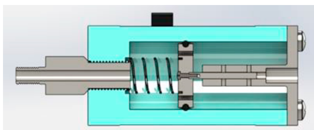

Fig. 18. Position of the plunger during the injection of air.

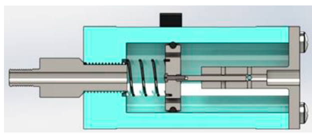

Fig. 19. Position of the plunger during the injection of grease.

Fig. 20 shows the complete system for injecting grease into the control cables. The pneumatic cylinder in the top lid of the reservoir 1 pushes the grease to the base of the injection line and the cylinder in the base 2 promotes the injection of the grease into the cable 3. Between the injection base and the injection needle of the grease in the cable is the air detection device (4).

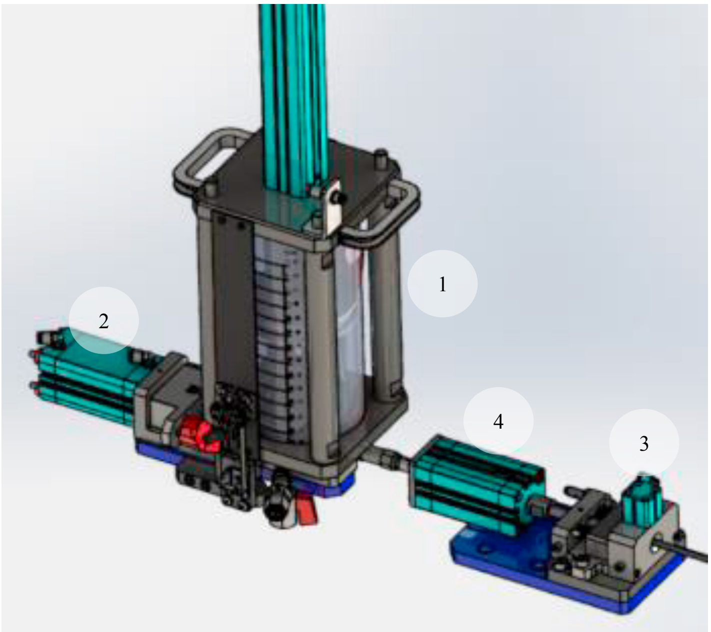

Fig. 20. Complete set of grease injection system on cables:
1: reservoir, 2: pneumatic injection cylinder, 3: cable positioning system, 4: air detection system.

Considering the total investment needed to implement the changes presented, and the total annual gain due to the improvements introduced, it is estimated that the pay-back time for the investment needed is approximately three years and five months. This study was based on 38 injection lines that operate for 252 days/year and with 3 shifts a day. Total investment includes:

- 8 bucket grease extraction systems and reservoir filling (Fig. 5 to 8);
- 6 transport benches of the reservoirs (Fig. 10);
- 1 bench to store reservoirs (Fig. 12);
- alteration of the 38 existing reservoirs and the bases of the injection lines (Fig. 13 to 16);
- manufacture of 38 substitute reservoirs for immediate exchange;
- air detection system for the 38 injection lines (Fig. 17 to 19).

In order to minimize the investment required to implement the proposed system, it was considered, whenever possible, existing components in the company, such as pneumatic cylinders, reservoirs and the bases of the injection lines. This option allows to reuse existing equipment from out-of-service systems, minimizing the impact to the environment, and optimizing resources, becoming the project even more sustainable

5. Conclusions

The system developed in this work for the injection of grease, in cables of control for the automotive industry, clearly extends the previously existing knowledge about this type of industrial operation, allowing to meet the established environmental objectives and preparing the industrial layout for future automation, in line with what is commonly referred to as the 4th industrial revolution. Moreover, this concept allows the integration of several operations understood as diverse so far, significantly improving the production management of one or more production lines. The concept, as well as being valid for this particular sector of activity, can easily be adapted to other industrial sectors where similar problems cause disruption of production line yields and damage to the environment. Thus, it can be state that this novel concept allows:

a. Reduce the waste of grease that constitutes a cost to the company and a damage to the environment. This goal is achieved by changing the disc which promotes the extraction of the grease from the bucket. In addition to the proposed system, which allows filling several reservoirs, the grease contained in a bucket is more quickly and fully used, avoiding waste caused and correspondent environmental contamination;
b. Use buckets with different dimensions. The claw system, on the platform that supports the bucket, allows the attachment of buckets with different diameters. However, the disc which promotes the extraction of the grease from the bucket must have a diameter depending on the inner diameter of the bucket. The height of the bucket depends on the stroke of the cylinders moving the previously referred disc;
c. Disassemble and assemble the reservoirs in the injection lines quickly and easily;
d. Simultaneously fill up to four reservoirs without stopping the injection lines. The filling process of the reservoirs is carried out outside the injection lines;
e. Easy storage of the reservoirs with grease, as well as the empty reservoirs coming from the injection lines;
f. Transport the reservoirs through the company to supply the injection lines with grease reservoirs and collect the reservoirs that have finished their working cycle using a milk-run system usually used;
g. Increase the productivity of the injection lines, reducing the stopping time caused by the reservoirs filling process. In fact, during filling of the reservoirs, which is a delayed operation for the reasons already pointed out, the injection line is not producing. Through the system developed in this work, this problem is greatly minimized by the direct exchange of an empty reservoir by another one previously filled with grease. This implies the existence of reservoirs in stock to replace the reservoirs that are in the injection lines. In addition, to implement this procedure the reservoirs must be easy to transport, assemble and disassemble from the injection line. The reservoirs are pre-filled with grease in the filling system and then placed on the storage bench (step 1). At the beginning of each work shift, the milk-run transports these reservoirs, properly conditioned in the trailer, to the injection lines where the reservoirs are exchanged (step 2). Thus, the reservoir which is still fixed to the injection line is removed, because it already finished its work during the shift, and then another reservoir filled with grease is installed. The stopping time of the injection line for this changeover is greatly reduced because only two clamps are required to remove or to assemble the reservoir on the assembly line. The reservoir that has been removed from the assembly line is put into the trailer to be transported to the storage bench (step 3) and placed in the filling system (step 4) as soon as possible, to be refilled. After filling, the reservoir is placed on the storage bench (step 5) and waits for it to be transported back to the injection line, repeating the cycle described and shown in Fig. 21;
h. The new device is able to detect the presence of air when the grease is injected into the cable, reducing problems caused by poor lubrication;
i. This development allows the elimination of considerable waste of grease throughout this process, which, in addition to the economic aspect, brought serious waste management problems which were harmful to the environment. Thus, the mass from the buckets is practically fully utilized, and the supply reservoirs do not even need to be cleaned, since the mass to be used is the same, a problem that is easily solved by assigning different colors to the reservoirs. Thus, the process becomes much more environmentally friendly, freeing companies from the problem of the management of harmful waste to the environment. Indeed, the cut in lubricant waste was higher than 70%;
j. Minimize the investment needed to implement the aforementioned improvements through the use of diverse existing equipment in the company.

A prototype of the system of mass injection in the cables was produced, including the air detection system. The prototype worked as expected, allowing to validate the idea and replicate it to the other equipment owned by the company. The transport system is still in the production phase. The system developed through this work shows how technical developments can be integrated equally with the logistics management systems of a manufacturing sector, improving their sustainability both in competitive and environmental terms. This work extends scientific knowledge in this particular area of control cable manufacturing for the automotive industry, but can be applied to other types of industry where the use of lubricants leads to problems of production management and environmental concerns. In addition, this system is suitable for centralized and automated management and can be integrated into a 4.0 Industry concept. Fig. 21 shows the flow diagram corresponding to the concept developed through this work.

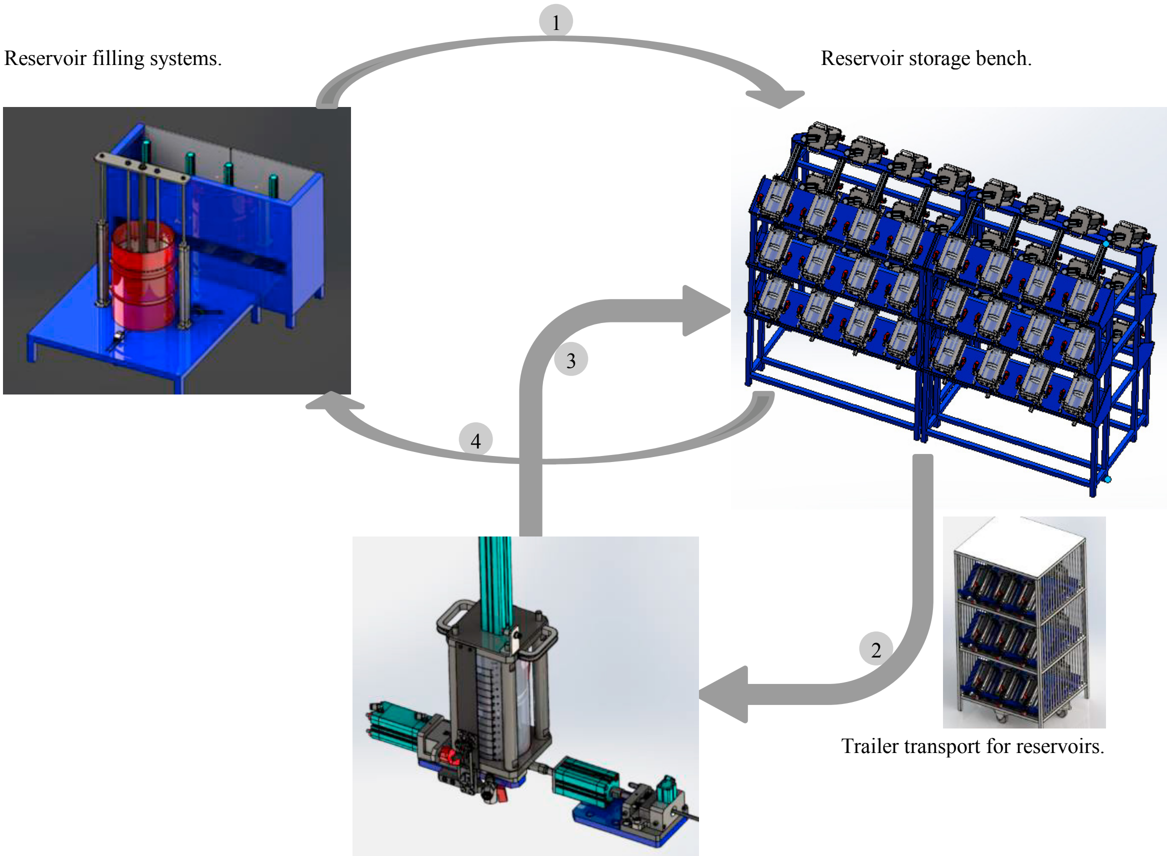

Fig. 21. Flow diagram of the reservoirs and filling/refilling process.

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