Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 38 (2019) 848–857

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

29th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2019), June 24-28, 2019, Limerick, Ireland.

A novel concept of a conduit transport system

P. R. Santos, F. J. G. Silva*, R. D. S. G. Campilho, G. F. L. Pinto, A. Baptista

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

Abstract

The automotive component industry has grown steadily in the last decade. The automation of the manufacturing processes has boosted an increase in the production rates of the components, and also contributed to a significant increase in quality. Automation has also contributed significantly to an increase in the production rate, as well as the process flexibility and reliability of the products obtained in the manufacture of spiral tubes used in control cables normally used for the operation of doors, brakes, glass handling, etc. . Currently, the manufacturing process of these components can be performed in a completely automated way, which proves the importance of automation in this sector. This work intends to present the development of a new solution for transporting conduits along an automatic production line, where several operations are carried out on the control cable spirals, namely cutting, deburring, punching of terminals at the ends and insertion of a tube starter, to sample noises during operation. An innovative transport system of the main sub-product (conduits) was developed along the line, which has a much higher reliability than previously recorded, also reducing the setup time required by 97%. The stoppages of the equipment due to problems with the conduits transportation process were also drastically reduced. The solution found is extremely simple and economical, allowing the reuse of numerous parts already used in the previous solution, with the consequent benefits in terms of resources reutilization. As an economical solution, it can be easily adaptable to other similar production processes, inducing very appreciable productivity gains.

Keywords: Automation; Mechatronics; Control cables; Automotive industry; Mechanical design; Process improvement; Assembly, Process.

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

2351-9789
10.1016/j.promfg.2020.01.166

1. Introduction

The automotive industry continues to be one of the sectors that most boost the world economy, which can be evidenced by the impressive number of vehicles produced during 2017: more than 97 million vehicles worldwide [1]. On the other hand, the strong degree of innovation associated with this sector forces numerous investigations in almost all areas, from the behaviour of materials [2-4] to the management of production [5-7]. The component industry supplying the assembly lines of the automotive industry is currently responsible for much of the development of the production process, with the task of making the processes sufficiently competitive, ensuring the required high-quality standards [8,9]. Competitiveness has required a growing increase in the automation of processes, progressively moving from a labour-intensive to an intensive-capital system, especially in developing countries, and wages tend to grow more noticeably, as well as in situations where the level of quality required is not compatible with variability linked to human behaviour. The cable industry has been heavily labour-intensive [10,11], but there has been a strong effort to automate more and more operations [12].

This work was based on the need to improve productivity and process integration in a plant dedicated to the manufacture of control cables for the automotive industry. The work intends to improve the transport concept already in use in some equipment responsible for the preparation of conduits. After all the changes made, the novel system needs to maintain its capacity to transport at once every conduit present in the machine and needs to be prepared for the different types of conduit that can be prepared, ensuring real flexibility and agility of the process. The equipment where the novel transport concept was tested has some differences to the standard ones that are already being used. Moreover, the novel equipment also needs to be prepared to receive later a system able to carry out another task usually performed by hand so far: the introduction of an external star-shaped tube, which is responsible for eliminating noise from the cable inside the car's structure. The conduits are commonly used in the door opening system of the car. These components are designed to protect and guide a steel cable that is responsible to open and close the doors in a car. To do that, the conduit is composed of a couple of layers with different materials and different functions. The exterior layer is made of LDPE (Low-Density Polyethylene) and its function is to protect the interior of the conduit. The second layer is made of steel, in a spiral shape, and intends to ensure the necessary mechanical strength and toughness to assume the desired layout into the body frame of the car or into the car door. Some conduits have a third layer responsible for ensuring low friction between the metal cable and the inner part of the conduit. In both ends of the conduits, there are injected plastic terminals, whose main function is to allow the attachment of the conduit to the door or structure of the car. There are different ways to attach the terminals to the conduit like ultrasonic welding, punching, plastic injection and even under pressure. However, in the equipment herein developed, the technology used to attach the both terminals was punching.

2. Literature Review

Process optimization studies in the component manufacturing sector for the automotive industry have multiplied over time due to the ongoing need to increase productivity and product quality. Araújo *et al.* [9] redesigned a manufacturing line of suspension mats for car seats, having eliminated two workstations that involved manual handling of by-products and product redirection on the line. In addition to the savings of human resources achieved by eliminating routine work, able to cause fatigue and leading to the generation of occupational diseases, an efficiency gain of 40% was achieved only by changing the concept of the production line. Nunes *et al.* [13] redesigned an assembly line of metallic parts used in the automotive windshield wiper motor. The study was carried out to minimize ergonomic problems caused by operator fatigue in short-cycle manual operations. Through the new system, important productivity gains were also obtained, with the cycle time being shortened from 12 to 7 seconds. In addition, operators have been spared the task of a low-value, error-prone task that causes fatigue and occupational diseases. Costa *et al.* [14], based on identical parts to the study presented in [13], with the same function but now in polymeric materials, has designed a completely different concept, extremely agile, which allows adapting to a wide family of parts, with very short setup time. This equipment only required the discharge of components in the equipment and the loading of parts already assembled, and the system is also able to control and separate the OK parts of the NOK ones. Magalhães *et al.* [15] designed a new system for collecting and reorienting newly bent wires by an automatic machine to promote the orientation of these wires to the next manufacturing stage: over-injection. With this system, a lot of cycle time has been saved because the robotic wire folding machine no longer needs to have a stop cycle just for another robotic arm to get the wire before cutting and position it correctly. Santos *et al.* [16] rethought the automation applied to an APEX machine used in the production of tire bead in the tire industry. The improvements introduced have significantly reduced downtime and equipment downtime, thus contributing to a significant increase both in the availability rate of the equipment and in its Overall Equipment Efficiency (OEE). In this case, the stop times were reduced by 62%. In order to solve recurring problems of quality in the assembly of a drive shaft for the operation of the car wiper, Costa *et al.* [17] developed fully automated equipment capable of receiving, guiding, assembling and controlling the assembly of these axes. In addition to solving the quality problems affecting the process, a productivity increase of 19% was also achieved, without the need to resort to robotics. The estimated payback time for the equipment was 2 years, a period that perfectly fits the legitimate ambitions of the sector's entrepreneurs. In the same line, Araújo *et al.* [18] developed an automatic system for application in guillotines, which allowed to eliminate the problem of deformation in the last part of each thin sheet to be cut. The system also has the advantage that it can be applied to guillotines already in use. Based on this study, the system was already implemented commercially. Based on the manufacture of bus structures, Castro *et al.* [19] developed a welding cell capable of fully welding the sides of a bus, taking advantage of a robot already out of service. This study, besides promoting an increase in the quality and reliability of the process, also allowed to promote the reuse of older equipment, perfectly sufficient to perform the tasks intended for this cell. In order to optimize the production of textile parts through automated systems, Santos *et al.* [20] designed equipment capable of cutting and baking textile parts in an expeditious and versatile way, significantly increasing the productivity of trades traditionally carried out in developing countries. Based on the same probe as this paper, Moreira *et al.* [12] developed equipment capable of integrating several operations that were dispersed by different equipment and workstations. This study allowed us to create a new concept of equipment in this sector of activity, capable of being easily integrated into the concept of Industry 4.0. As can be seen from the studies mentioned here, there is a strong need and demand for process automation. If the main automobile assembly lines are already very automated and robotized, most of the component manufacturing industries still face productivity, quality and transition problems from traditional labour-intensive systems to capital-intensive systems. Taking a step forward, it is necessary that equipment is already designed to integrate the new concepts of industry 4.0 [21].

3. Methods

This work intends to develop a new concept for the transport of a conduit from the beginning of the equipment to its end, where other operations are triggered, in order to produce the control cable. The system already in use was observed for a long period of time and all the problems detected were studied individually for a better understanding of the causes of each detected problem. When the investigation phase was completed, a strategy was elaborated to solve as many problems as possible and to try to simplify the mechanism, making it easier for future interventions and updates of this system. This new concept can also be adapted to other equipment with different functions beyond the one shown through this study.

3.1. The problems detected

In a system that produces continually conduits with punched plastic terminals, there is a need to make the cycle time as short as possible leading to increasing the daily production. A standard machine that produces this kind of components can have between 10 to 15 workstations which means that the machine has a maximum of 15 conduits been worked every time. The current system installed in the studied equipment has a conduit every 25 mm distance (Fig. 1) which means that in equipment with a total length of 4.5 m, for example, it will exist 180 conduits being processed every time. It means that only 8% of the conduits present in the machine are been worked. This 8% is a very small percentage so there is a room from improvement in this perspective. Other problem noticed was the difficulties on the assembling of the conduit transport system throughout the equipment. The current system is divided into two systems: one is attached to the part of the machine that is fixed and the other part is attached to its moving part. Because there is no connection between these two parts, it is very difficult to assure that both sides are placed in the exact same position. This adjustment process can take several hours until both parts are aligned, which induces elevated cost to the manufacturer. Thus, there is one more opportunity for improvement.

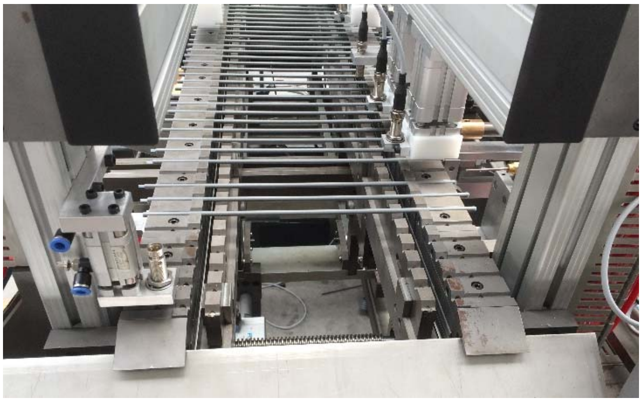

Fig. 1. High number of conduits in the equipment.

In addition to the two topics explained above, there is a third topic which was not mentioned yet. This transport system can be also used in other types of machines that can have a varied number of workstations. This means that the system needs to be adjusted according to the needs of the design engineer. Because of the complexity of the system, it is hard to adjust it to other types of machines with different lengths. Thus, another improvement that can be made is to create a standard model that can be adapted to several machines provided with different sizes. However, a problem was detected in one of the levers that compose the mechanism (Fig. 2). The systematic contact between the lever and other surfaces causes a deterioration of both parts, which will eventually oblige to a maintenance stoppage to replace both worn components. Because of the time spent in these breakdowns, and due to the complexity of the repairing tasks, it was decided to eliminate this part of the mechanism from the newly designed one.

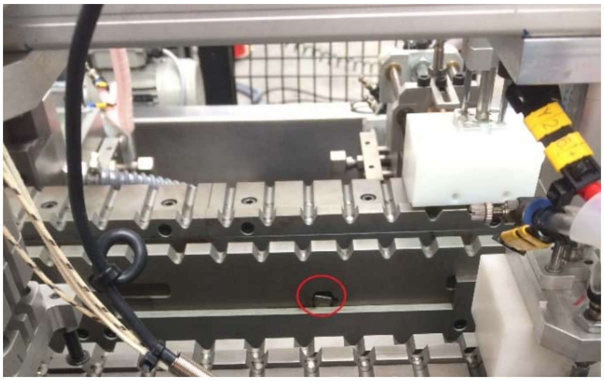

Fig. 2. Problem identified in one of the levers included in the mechanism (red circle).

3.2. Design Steps

The design of the new concept was divided into three steps. The first step consists of establishing the main requirements for the new concept. Because the previous design presents some problems, it is necessary to establish whose are the most important to solve. The order of problems to solve is described below:

- The high amount of conduit that is in progress into the machine, but is not being worked;
- The difficulties in the assembly process of the equipment that can take several hours just to adjust both parts of the mechanism;
- Create a new concept which can be easier to adapt to other machines without having any problems with the length of some components, which create some concerns in the previous version of the mechanism.

The second step of the process consists of finding a solution for every problem written above. In this step, the important idea to retain is that problems can be solved individually. The second problem identified was studied only when the first one was already solved and so on. The final step of the process consists of combining all the solutions found previously into one whole system that presents no longer the identified problems. If it was not possible to solve all the problems, the hierarchy written in the step one of the process will dictate which are the priorities and the new concept will need to be adapted to make sure that at least the most important problems are solved. Throughout this process, there was a try to utilize as many components that are already part of the mechanism as possible.

4. Results and Discussion

4.1. Previous concept

An additional effort to keep as many already existing components as possible was done because the mechanics of this system works well and there is no need to redesign the whole mechanism. The previous mechanism (Fig. 3) is composed of two separate modules, the first one (Fig. 4) is responsible for the activation of the levers that will move the second module of this system. The working principle presented in the first module of the mechanism is very simple: when the cylinder on the left side is activated, a lever will elevate the second module which is able to hold the conduits (Fig. 5). When all conduits are raised, the second cylinder contained in this equipment will activate another lever that will transport the conduit from one workstation to another (Fig. 6). This second step of the mechanism had to be completely removed.

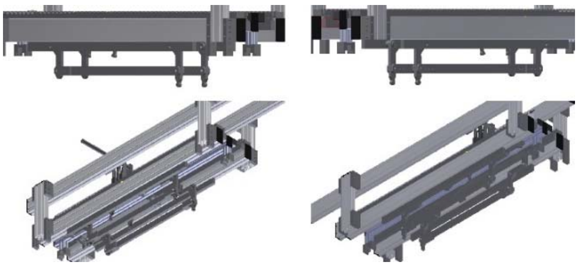

Fig. 3. The previous equipment.

Fig. 4. First module of the current system

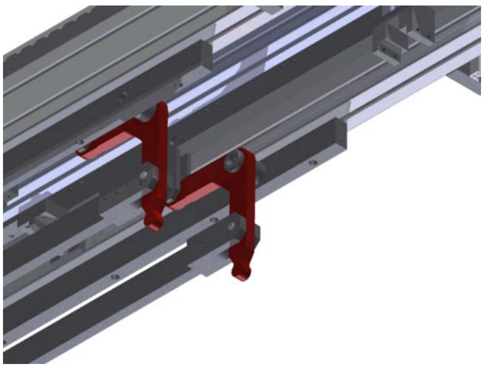

Fig. 5. Lever that will raise all conduits.

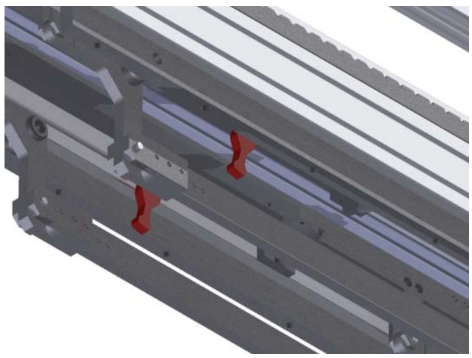

Fig. 6. Lever that will make the conduits move from one workstation to another.

The second module which is part of this system is composed of several parts, all very similar (Fig. 7). These parts will receive the conduits and will transport them thanks to the levers system already mentioned.

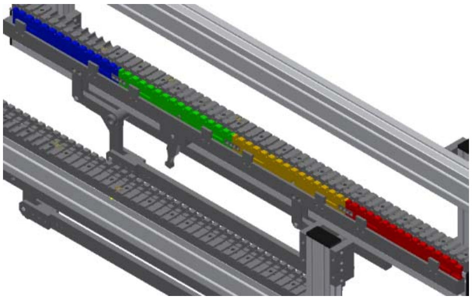

Fig.7. Components those are responsible for accommodating and transporting the conduits.

This is the concept previously used. For the new one, some parts of the first module like one of the levers and one of the cylinders were utilized, and the second module had to be completely redesigned due to all the problems that the components with high length were causing, and because of the reduced moving length.

4.2. Novel approach

The first problem to be solved was the lower percentage of conduits that are being worked into the machine. The cause of this problem is the moving length of the system because it obliges to have a conduit each 25 mm. The solution adopted goes through the increase of the moving length from 25 to 100 mm. This allows the percentage of conduits to increase from 8% to 34%, which is a significant improvement. To achieve such an important improvement, the solution found is based on a system with linear guideways and a cylinder responsible for the moving length of the entire system (Fig. 8). In the previous concept only the components responsible for holding the conduits are moving but, with the novel solution found, the whole system can be moved because it is supported by linear guideways. This allows the increase of the moving length from 25 mm to 100 mm, for example. To do this, the only thing that needs to be done is to add a cylinder with a stroke of 100 mm and connect it to the transport system. Another advantage of this solution is that the moving length can be adjusted from machine to machine because of the flexibility that this novel concept allows because, if there is a need of a higher moving length the only component that needs to be changed is the cylinder.

The next problem that was solved was the assembling difficulties due to the adjustments which need to be done to keep the whole system working properly. A problem that occurs many times during the assembling stage of this system is that the components attached to the fixed part of the machine, and the components attached to the moving part, are completely unsynchronized (Fig. 9).

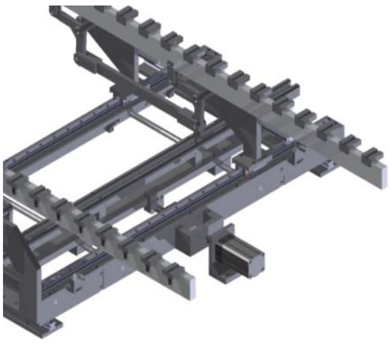

Fig. 8. The solution found for the low number of conduits being worked.

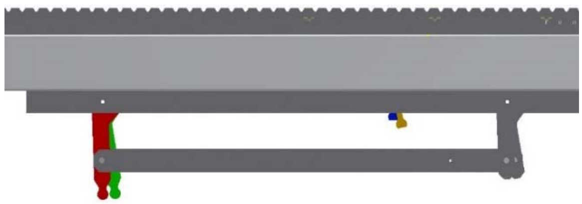

Fig. 9. Assembling difficulties due to desynchronization.

As can be seen in Fig. 10, there is no way to assure that both parts of this system are fully aligned. Thus, the adjustment process must be repeated several times until both parts are perfectly aligned. This can take several hours, which can be very expensive to the company and can lead to delays in the assembling process. To solve this problem a few modifications needed to be done to the whole model. All modifications done are identified below:

- Both the fixed and the moving parts are no longer screwed to the aluminium profile;
- A connection that allows an easier adjustment of both parts was designed;
- Although the moving part of the system is no longer attached to the machine, there is still a need to make sure that when the machine is adjusting its length to produce another type of conduits, the transport system can be adjusted as well.

In Fig. 11 is shown the system after all modifications described above are completed. Both the fixed and the moving parts are no longer screwed to the aluminium profile but, instead was created a new connection that allows the whole system to move forward. To do that, a solution based again on linear guideways was adopted. When the cylinder responsible for the moving length of the whole system is activated, all system advances the linear guideways that are attached to the aluminium profile, providing better guidance (Fig. 12).

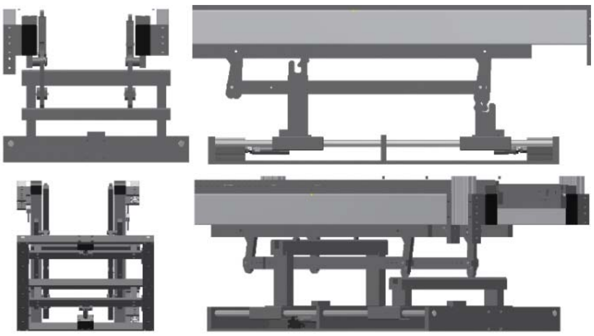

Fig. 10. Problem with the system assembling.

Fig. 11. System after all modifications.

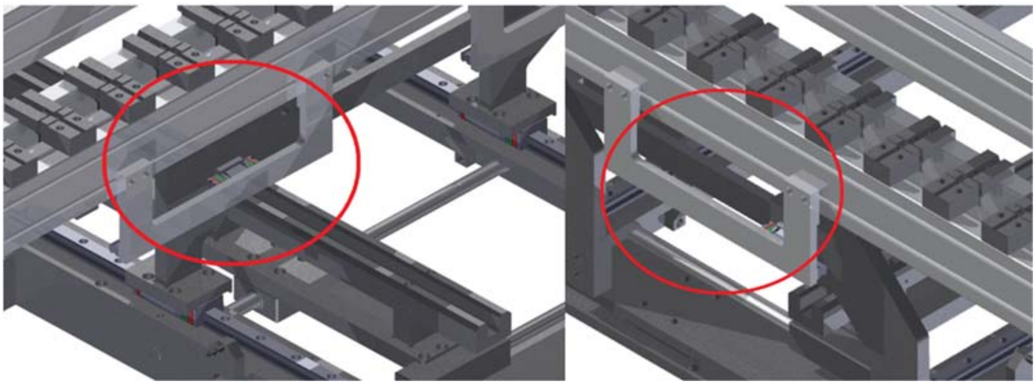

Fig. 12. Linear guideways attached to the aluminium profiles for better guidance

To reach an easier adjustment between the fixed and the moving parts, it was added a new set of linear guideways that will support only the set of components placed in the moving part (Fig. 13). This allows a much easier adjustment process because all the components have now somehow a connection to each other, which guarantee that all components are in place. The fixed part was modified too, and now it is screwed to the module responsible for the activation of the cylinder that will activate the lever (Fig. 14). The linear guideway that was added will also allow that when all machine is adjusting its length to produce conduits with a different size, the transport system can also be adjusted automatically with the machine.

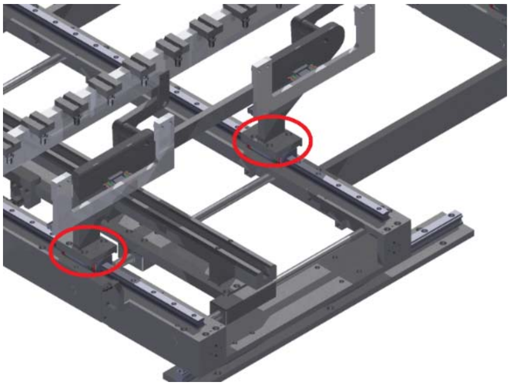

Fig. 13. Connection between the moving part and the remaining system.

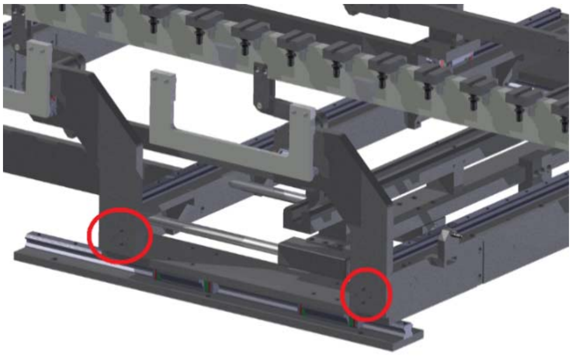

Fig.14. Connection between the fixed part and the remaining system.

The last modification made to this system was performed with the intention of reducing as far as possible the length of some components that can deform during its work and can cause the machine breakdown several times, which affect the production rate of the entire machine. The components that suffer from these problems are the ones that will accommodate the conduits and transport them. The high length and the elevated weight are the main cause for these problems, so the solution goes by the reduction of the length and, if possible, also a change of material. To solve the length problem, the solution goes through the division into working modules (Fig. 15) that are attached to each other and work at the same time. Thus, the components that accommodate and transport the conduits are smaller and the problem related to its deformation is less likely to happen. Other action that was taken to reduce this problem, even more, was the change of the material from steel C45E to Aluminium alloy (6xxx series). This change of material will not compromise the integrity of the whole machine.

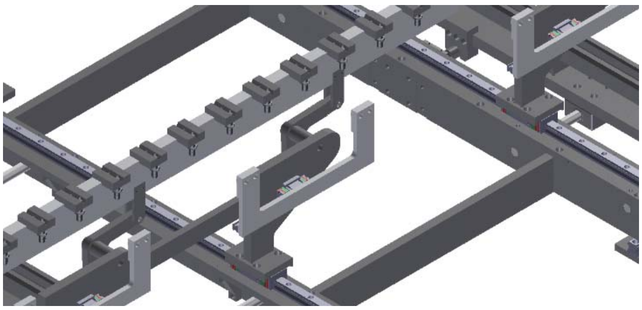

Fig. 15. Components that enable the division into working modules.

After all the modifications that have been done, it can be stated that all the problems identified were successfully solved and the main goals of this work are all achieved. The mechanics of this novel system remains fairly simple as well. Each one of the three modules that compose the transport system has a cylinder that will activate the levers, which correspond to each module of the mechanism (Fig. 16). Then, another cylinder will push the three modules at the same time, transporting all the conduits from one workstation to another (Fig. 17). Another problem that was solved was the cleaning issue. Almost every day, when the machine is turned off, it is required some cleaning at the levers mechanism. The dust and the trash that some workstations in the machine can cause can accumulate in the transport system, which may lead to malfunctions. Now, all the workstations that produce trash have a tubing connected to them that will transport all the trash into a recipient. The linear guideways were carefully chosen because of this problem and all blocks were selected with high dustproof resistance. In terms of the complexity of the automation, it is still very similar to the system previously used. The only difference is that this novel system allows the sensors that detect the presence of the conduits to be integrated into the mechanism, unlike what happened in the old system. For any reason, if it is necessary to remove or replace any sensor, the access to them is also very easy, which make the stop very quick and allows the machine to be in working conditions as much time as possible.

Fig. 16. Cylinder present in each one of the modules.

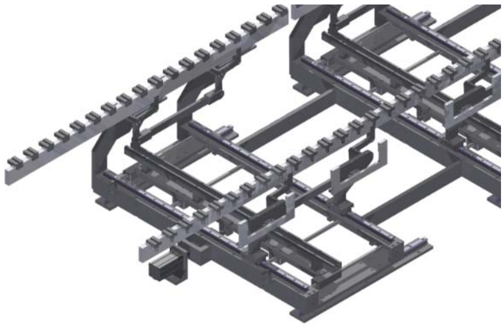

Fig. 17. Cylinder that will move all the modules that compose the new system.

The extension of the step for the series of conduits in simultaneous processing also allowed to create the space necessary for a new module to be developed and to be connected to the equipment, which allows the introduction of the star tube to reduce the noise caused by the cable inside of the car's structure. This will be a development to be made in the next job.

Unlike other works such as [9,12,13,14], this work did not aim at reducing cycle time in order to increase productivity, but rather a transport systems simplification of the main by-product along the equipment, where it will undergo several manufacturing operations. However, it can be considered that this work is in line with [16], because the main causes of equipment's breakdowns have been eliminated, being expected a reduction of about 70% regarding the breakdowns history of the first version of the equipment, being also notorious the reduction of the setup time, as in [11], which will be reduced from about 5 hours to 10 minutes regarding the reduction of tasks needed and the simplicity included in the new design taking into account the setup operations, that is, a reduction of about 97%. As in [17, 18], the quality of the processed product will be greatly benefited.

5. Conclusions

This study was based on equipment in which several operating gaps had been identified, which significantly affected its performance. Through innovative mechanical and pneumatic solutions, the problems have been solved, and it has been possible to implement a new conduit transport system along the production line, reducing the number of by-products in the process of manufacture and extending the space for other modules to come to be coupled to the base equipment in the future. The solutions found are extremely simple and economic, showing that high investments are not necessary to achieve very significant results in terms of productivity. The moving length was augmented from 25 mm to 100 mm, allowing to deal with different products without the problems identified in the previous version. Moreover, some systems containing parts that were subject to more wear and tear were changed, eliminating most of the causes responsible for the successive stops that were typical of the initial equipment. The new system developed was designed to significantly increase the flexibility, so required by current market conditions, dramatically reducing setup time (97% reduction). It was also possible to improve other details of the equipment, in particular by introducing a system of suctioning the produced debris, thus reducing the risk of equipment stops due to an accumulation of debris in critical areas. The new design also took into account the ease of maintenance, making it easier to access systems that may need to be replaced in a short-term.

This work contributes to the expansion of knowledge in the area of automated equipment solutions, which, when properly utilized, can lead to substantial economic and equipment availability gains without the need for significant investments. There was also the environmental and technical care to make the most of the existing parts in the previous equipment, so that reuse can be taken into account.

Acknowledgements

The Authors want to thank the PR Metal, Lda. company, namely Mr. Mário Cardoso, due to the data provided, as well as the availability to welcome M.Sc. students from ISEP to carry out their Master's Thesis.

References

[1] OICA - International Organization of Motor Vehicles Manufacturers, 2017 Production Statistics, URL: http://www.oica.net/category/production-statistics/2017-statistics/. Accessed on 03rd of February, 2019.

[2] T. Gomes, F. J. G. Silva, R. D. G. S. Campilho, Reducing the simulation cost on dual-phase steel stamping process, Procedia Manufacturing 11 (2017) 474-481.

[3] C. R. M. Silva, F. J. G. Silva, R. M. Gouveia, Investigations on the edge crack defect in dual-phase steel stamping process, Procedia Manufacturing 17 (2018) 737-745.

[4] H. Pinto, F. J. G. Silva, Optimisation of die casting process in Zamak alloys, Procedia Manufacturing 11 (2017) 517–525.

[5] C. Rosa, F. J. G. Silva, L. P. Ferreira, T. Pereira, R. M. Gouveia, Establishing standard methodologies to improve the production rate of assembly-lines used for low added-value products, Procedia Manufacturing 17 (2018) 555-562.

[6] P. Guariente, I. Antoniolli, L. P. Ferreira, T. Pereira, F. J. G. Silva, Implementing autonomous maintenance in na automotive componentes manufacturer, Procedia Manufacturing 13 (2017) 1128-1134.

[7] I. Antoniolli, P. Guariente, T. Pereira, L. P. Ferreira, F. J. G. Silva, Standardization and optimization of an automotive components production line, Procedia Manufacturing 13 (2017) 1120–1127.

[8] B. Barbosa, M. T. Pereira, F. J. G. Silva, R. D. S. G. Campilho, Solving quality problems in tyre production preparation process: a practical approach, Procedia Manufacturing 11 (2017) 1239 – 1246.

[9] W. F. S. Araújo, F. J. G. Silva, R. D. S. G. Campilho, J. A. Matos, Manufacturing cushions and suspension mats for vehicle seats: a novel cell concept, International Journal of Advanced Manufacturing Technology 90 (2017) 1539–1545.

[10] C. Rosa, F. J. G. Silva, L. P. Ferreira, Improving the quality and productivity of steel wire-rope assembly lines for the automotive industry, Procedia Manufacturing 11 (2017) 1035–1042.

[11] C. Rosa, F. J. G. Silva, L. P. Ferreira, R. Campilho, SMED methodology: the reduction of setup times for Steel Wire-Rope assembly lines in the automotive industry, Procedia Manufacturing 13 (2017) 1034–1042.

[12] B. M. D. N. Moreira, Ronny M. Gouveia, F. J. G. Silva, R. D. S. G. Campilho, A Novel Concept Of Production And Assembly Processes Integration, Procedia Manufacturing 11 (2017 1385 – 1395.

[13] P. M. S. Nunes, F. J. G. Silva, Increasing Flexibility and Productivity in Small Assembly Operations: A Case Study, In: Advances in Sustainable and Competitive Manufacturing Systems, A. Azevedo (Ed.), Lecture Notes in Mechanical Engineering, Springer, 2013, pp. 329-340: DOI 10.1007/978-3-319-00557-7.

[14] R. J. S. Costa, F. J. G. Silva, R. D. S. G. Campilho, A novel concept of agile assembly machine for sets applied in the automotive industry, The International Journal of Advanced Manufacturing Technology 91 (2017) 4043-4054.

[15] A. J. A. Magalhães, F. J. G. Silva, R. D. S. G. Campilho, A novel concept of bent wires sorting operation between workstations in the production of automotive parts, Journal of the Brazilian Society of Mechanical Sciences and Engineering 41 (2019) 25.

[16] R. F. L. Santos, F. J. G. Silva, R. M. Gouveia, R. D. S. G. Campilho, M. T. Pereira, L. P. Ferreira, The improvement of an APEX machineinvolved in the tyre manufacturing process, Procedia Manufacturing 17 (2018) 571-578.

[17] M. J. R. Costa, R. M. Gouveia, F. J. G. Silva, R. D. S. G. Campilho, How to solve quality problems by advanced fully-automated manufacturing systems. The International Journal of Advanced Manufacturing Technology 94 (2018) 3041–3063.

[18] L. M. B. Araújo, F. J. G. Silva, R. D. S. G. Campilho, J. A. Matos, A novel dynamic holding system for thin metal plate shearing machines, Robotics and Computer--Integrated Manufacturing 44 (2017) 242–252.

[19] André F. Castro, M. F. Silva, F. J. G. Silva, Designing a robotic welding cell for bus body frame using a sustainable way, Procedia Manufacturing 11 (2017) 207-214.

[20] P. M. M. Santos, R. D. S. G. Campilho, F. J. G. Silva, Design of a novel equipment for automated clothing manufacturing, Procedia Manufacturing 17 (2018) 766-773.

[21] M. Barbosa, F. J. G. Silva, C. Pimentel, R. M. Gouveia, A novel concept of CNC machining center automatic feeder, Procedia Manufacturing 17 (2018) 952-959.