AUTOMATION OF MANUFACTURING CELLS FOR AUTOMOBILE ASSEMBLING

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Abstract: *The brazilian automobile industries experience an increasing need of manufature automation, production volume and flexibility when compared with the former lines. This paper aims to present a successful case of technological innovations adopted for the launchings of new vehicles focusing specifically the assembling of their bodies in white(BIW) by LASER joining cells. Here one of the most significant innovations has been the introduction of a Nd-YAG LASER beam source on the joining process, adopted in order to improve the finishing quality of the roof joining and assembling quality. The development of these new cells has demanded brand new conceptions and designs in order to assure a world class geometrical and metrological quality control during the whole cycle. They operate 16 robots, one controller and security subsystems, quality control, diagnose and communication operating on heavy duty conditions under a massive application of LASER process. Their architecture is based on resources optimization as well as on Lean Manufacturing concepts, resulting on improved reliabilities, operability, lower down times, higher flexibility and product quality. The cell control description emphasizes the main controller structure (PLC) and its logic based on SDE (Systems of Discrete Events) and a LADDER standardized block language. This standardization hasn't only allowed for an improvement of the reliability and economy of resources regarding scale effects as well as code flexibility, but also has improved the faults detection during the whole assembly process. It is explained how the HMI (human machine interfaces) interacts with the others levels of the production systems, i.e. how the supervisory operate into them.*
Keywords: *Welding, Automation, Laser, Manufacture.*

1. INTRODUCTION

The automobile industry has, all over the world, found a rising increase in the competition among many companies of this sector during the years of 80 and 90. This competition has presented itself through an exceeding capacity and by its search for smaller costs in emerging countries. Regarding the Brazilian market, some factors have aggravated this setting: The entrance of many new brands and assemblers, lack of an industrial policy and high levels of inflation. In 2001, with the increased competition and an almost stagnation of the growth, the idleness was from 40 % to 50% [1]. Due to this setting, more than ever the innovation, quality and reaction capacity to the needs and desires of the client are survival conditions in the market. From the performance point of view, it is essential to mention the indicator that are, in the conception of TAKASHINA & FLORES (1996) [2], forms of numerically represent characteristics of products and processes. For MUSCAT & FLEURY (1993) [3], quality performance indicators are mechanisms that show if the organization is being competitive as to the demands of their clients. In the vision of these authors, the main indicators that should be incorporated in all the processes and that establish the minimal conditions for the performance in the market are: Cost, quality, flexibility, low time of productive cycle and innovation. Searching for the competitive advantage that became, in this setting, the ability of the assemblers to spend less and offer more through a better use of production techniques, there were, mainly in the last 10 years in the Brazilian assemblers, investments in technology of modern production, the same adopted by the head offices in Europe and United States. One of the enablers for these investments was the technological qualification that permitted the assemblers to present themselves as potential absorbers of these t-echnologies. The technological qualification strengthened the Brazilian assemblers in comparison to the headquarters and today a great part of the global projects have the participation of the Brazilian engineers, (this has showed to be a tendency mainly in the case of consolidated assemblers as Ford, GM, and VW of Brazil, this last one being the setting for this case study). All of these contradicting some hypothesis that the globalization would make dispensable the engineering in Brazil, on the contrary, the Brazilian engineering has an important role of technical support to the global operations. Counting on a research and development center more equipped than many developed countries as Spain and Australia (VILLARDAGA, 1999a) [4]. According to VILLARDAGA, the Brazilian automobile industry becomes more and more a technological exponent for the other emerging markets. VILARDAGA (1999b) alerts to the fact that the technological innovation conducted by the automobile industry in the decade of 90 in Brazil is not a synonym of technology supported only in the automation, but in industrial projects with intelligent solutions. Focusing the productive means, to reduce costs for implantation of terms for the launching of new products demands a manufacture engineering with a technological qualification that answers to these demands and also guarantees the quality of the products. This papers aims to present a successfull study case of automation of manufacturing cells for the assembling of automotives body in white usinge laser joining technologies at the brazilian plant of a world class automotive industry.

2. LASER JOINING TECHNOLOGY FOR AUTOBODIES (BIW) ASSEMBLY

The search for a competitive differential seeking to answer to the needs and the desires of the client, the automotive engineering and the manufacture processes have progressively presented innovations. The main ones are the aesthetical and those related to the economy of fuel and security. Both the seeking for complex and innovating designs and the reduction of the weigh of the body holding the resistance to impacts, took the studies on new light materials and new technologies as the welding Tailored Blank (TB) and the hydroformation and mainly new welding technologies [5-8]. Among the most recent technologies adopted in the welding of automotive bodies the LASER welding stands out, for this that is relatively recent permits to make a precision, quality, and resistance welding that are superior to the conventional ones. That is all are because it maintains the proprieties to the maximum for it has a low zone affected by the heat and for having a high penetration and high repeatability and accuracy, and precision [9]. Following are described some of the main advantages of the adoption of the LASER welding in the automotive area:

- Fast welding speed of > 5 m/min, which translates into higher productivity;
- Excellent reproducibility of the joints;
- Minimal heat input, hence less distortion and less refinishing required;
- High joint rigidity of the continuous seam, with positive effects on crash behavior;
- Good access to the welding points thanks to non-contact processing;
- Weight savings through the use of Tailored Blanks;
- The laser lends itself well to automation and is easy to integrate into system concepts.

Due to these characteristics the LASER welding appears as a promising technology for the welding of automotive bodies and surely will still need a lot of research and improvement in the next decades. In Figure 1, it could be seen the evolution of LASER welding in comparison to other technologies during the last decades. Considering the most recent typical automotive bodies, it is very common to and around 4500 resistance spot welds, many meters of MIG and MAG weld beads and also few meters of LASER weld. In some assemblers, the average of LASER used in a body is around 20 to 30 meters, including the “tailored blank” weld. And in some cases, it has replaced the MIG/MAG weld and weld points for resistance. One of the great advantages of the LASER weld is that it is only necessary the access to one of the sides for its application. This characteristic permits it to be projected bodies with smaller quantity of reinforcements that are necessary to compensate the flaws and holes that are necessary when we work with welding pliers, making it possible an economy due to a lesser quantity of material and, consequently weight, improving also the body performance.

3. Nd:YAG LASER WELD JOINING AUTOMOTIVE BIW

Among the existing technologies for LASER for welding the one that has stood in the latter years has the Nd: YAG (Neodymium, Yttrium, Aluminium Garnet). The type used in the welding of bodies is the one of continuous wave (CW) and has presented itself as the most versatile for the industry, because of its characteristics of high absorption by transition metals (ex. Iron, nickel, and titanium) and steel alloys. Fig. 2 presents a division of market of the different LASER technologies.

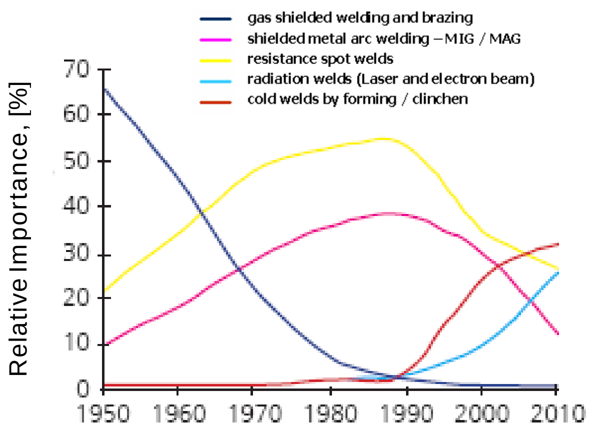

Figure. 1: Trends for joining processes in automotive body in white assembly, disregarding conception type (steel, aluminum space frame or multimaterial conception). [10]

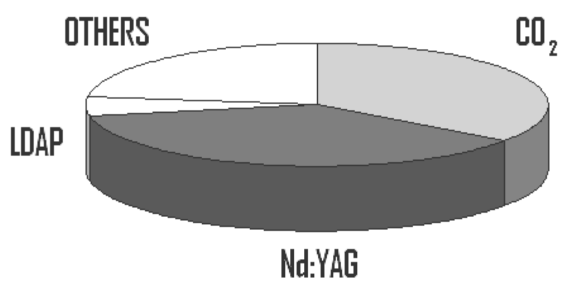

Figure 2. Market share for laser technologies, forecast for 2004. After Anderson[11].

With the progresses in the domain of this technology, many automobile industries decided to use laser in geometry stations of body welding, which is our object of study. The main advantages of a BIW welding cell using Nd:YAG are described below:

- Spatial flexibility: The flexibility in the application is permitted by the use of the optical fiber for the transmission of the optical beam by robots or other articulated devices.
- Easy access: Due to the small dimensions of the optics it is possible to reach the main areas of the body to be reached in the welding process.
- Robots of application of small bearing: Due to the low weight of the optical headstocks, in comparison with the conventional equipments of welding, it is possible to use robots of smaller dimensions and capacities.
- Reduction of physical area: Due to the use of robots of small bearing and the access easiness of the headstocks, it is possible to reduce the installation areas. The geometry cells of LASER welding with more than 15 robots in an area of 65 m^2 is common, which would be impossible with the use of conventional welding methods and equipment.
- The interchangeability of robots by source: Through the switching of optical exits it is possible to use an only source for many robots alternately.

4. AUTOMATION OF GEOMETRY-CELLS USED ON BIW LASER ASSEMBLING

The geometry station of this study – known as LGG (LASER Gross Geo)- has the following basic constructive characteristics described below:

- 2 welding cabins, being LGG1 (16 robots) and LGG2 (12 robots).
- 3 PLC (programmable logic controllers): 1 for each cabin and 1 for sources switching control.
- The robots are divided in three types: 12 of them are 7-axis 250 N load; 4 are 6-axis 250 N load; 12 are 3-axis 300 N load robots.
- 7 sources of LASER shared between two composed cabins each, with a chiller station to guarantee the cooling of the cavities.

The main geometry component in order to guarantee a perfect laser welding accomplishment is the body subjection into the process. Thinking of this theme as a main project subject, a vertical movable table was built to lower the body and fasten the body floor. After the table movement, two geometry devices reach the side parts of the body and take them to the right position throw a hydraulic device (Figure 3). Finally, after the floor and sides fastened, a geometry device for the roof is applied (Figure 4). This fasten condition is so important that very small differences in their positions would lead to make the process unfeasible because the laser beam focus would be out of range. The geometry station is a completely closed safety cubic shaped cabin with 400 m^3. Loading and unloading process is made automatically through a skid roller transport. To comply with the product specifications, as well as to the required volume and mix by the production planning, the performance described below is expected from each one of the cabins:

- Use of 3,100 mm of brazing bead in the roof with the addition of material.
- Use of 3,580 mm of weld beads witho ut the addition of material.
- Comply with the production of 600 bodies daily, in 3 models of cars.
- Operate ~ 290 pneumatic devices for the correct positioning of the body parts that will be welded.
- To have availability of 85%. In Figure 5 presents the disposition of availability.
- To serve a time of cycle of about 75 s. Figure 6 shows the ideal distribution expected for each cabin.

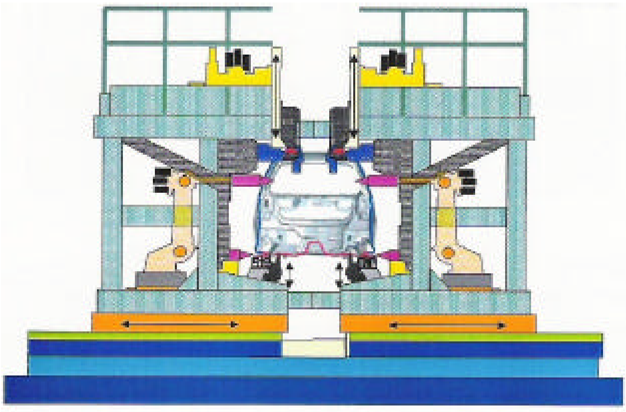

Figure 3 - Automotive BIW - laser geometry station. Arrows show subjection movements.

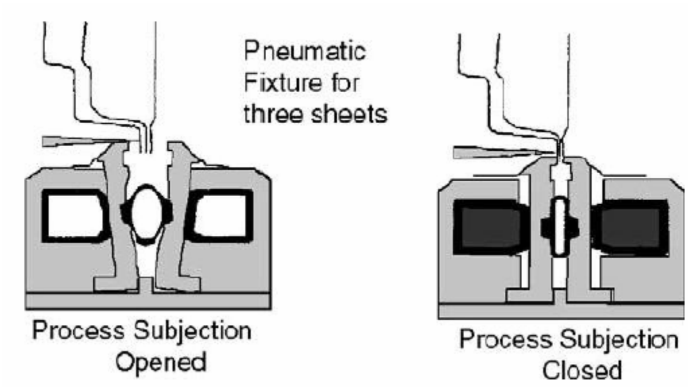

Figure 4 - Two stages subjection for floor and side panel parts.

Due to the a complexity of this installation, and to comply with all these requirements, it is necessary a high performance control that synchronize all the devices that are part of this system, as well as having an interface with the operators that assess the manual and automatic control and diagnosis information of operating flaws. For this, it is essential to project an effective automation architecture. In Fig. 7 it can be seen an example of architecture of a such a welding automatic cell. From the architecture it could be classified some essential elements that influence the performance of an automatic welding station: the PCL (Programmable logic controller) and the HMI (human machine interface).

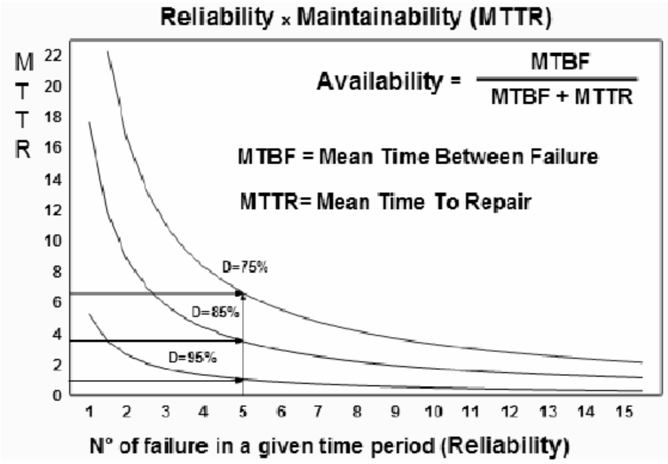

Figure 5 - Time reduction for corrections on flaws and undesirable pause, increasing the availability.

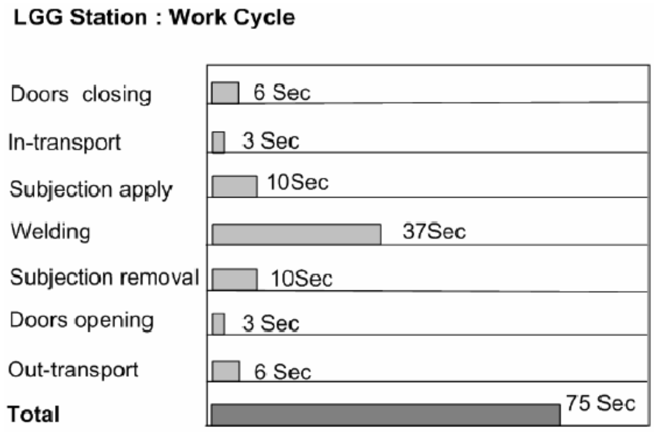

Figure 6: The ideal operation time distribution for each LASER welding cabins.

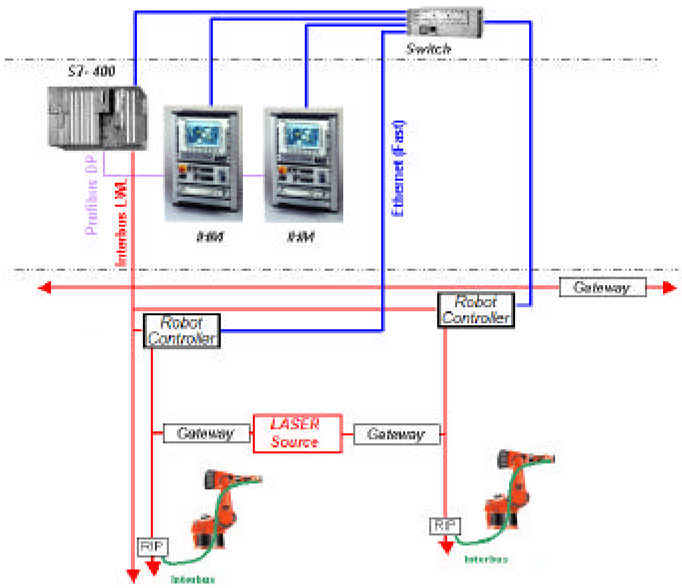

Figure 7 - : Architecture of the automation system of a welding automatic station.

5. PLC (PROGRAMMABLE LOGIC CONTROLLER)

The PLC has its role as the system maestro. Besides controlling its own periphery, it is responsible for the synchronism of the actuations of all the other equipment of the station, as the robots, the LASER generator sources and other controllers and human security devices (security fences, scanners and security light curtains). We present below the main characteristics expected from a PLC [12]:

- High level languages programming classified by IEC 61131- 3 [13], guarantying a market dominion of programmers programming and friendly to the maintenance technicians.
- Operational trust.
- Advanced functions. An adequate controller can perform a great variety of control tasks through the mathematical, quality control, information for reports functions. Production management systems are very improved with the use of the controllers.
- Net communication. Through the operation interfaces, the net controllers and computers permit the assessment of data and an enormous interchange of data sharing with other controllers, with the robot or welding equipment that form the system as well as with the HMI interface.
- The implementation of an automation process of an automatic station should start as the beginning point of a coherent plan of function with all the operations and the control modes (Fig. 8).

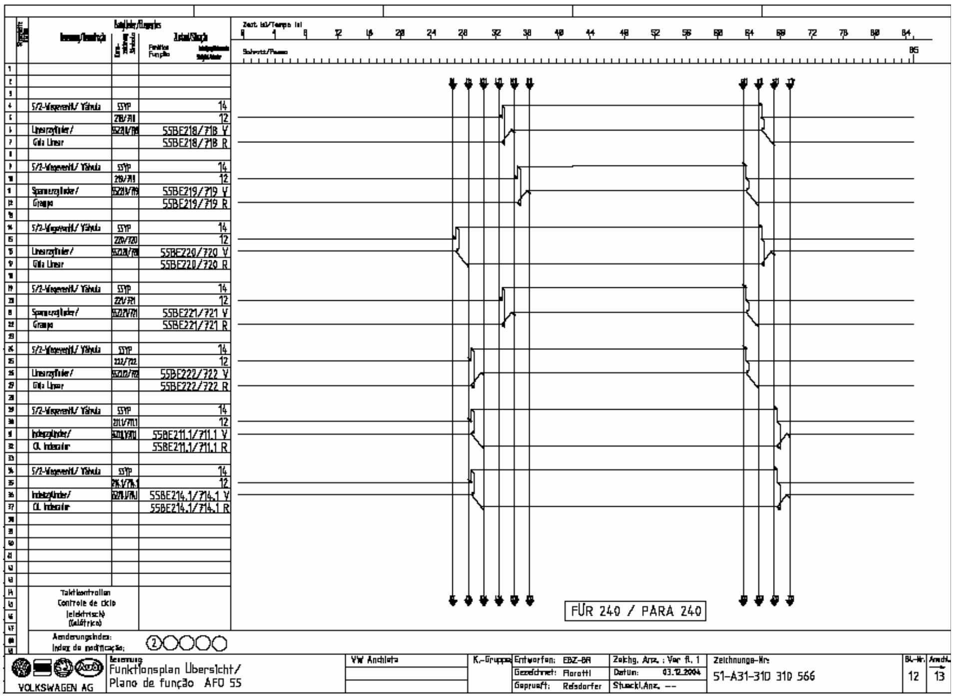

Figure 8: Function plan using a path step-chart of one of the operations of the LGG stations.

A logic controller for an automatic machining system has multiple control modes: typically auto, hand, and manual. In the auto mode, operations are executed automatically except when faults are detected; then the machining system must stop. Hand mode is used by the operator to coordinate multiple stations or validate the automatic process step by step. In manual mode, the operator has single station fine operation control (such as jog motions) which is used for fault recovery [14]. In current industrial practice, the specification of normal operation cycle is given by a timing bar chart, especially when it deals with a station with a degree of complexity and with a great number of performers, a lack of synchronism in the setting in motion can mean a considerable loss of time in the station final cycle. In Fig. 9 we have a time chart of one of the stations in automatic cycle, in this case the tool used was the Microsoft Project, due to the great need of optimization. Using a timing bar chart, logic controllers for the normal operation can be modeled [15]. However because faults occur, each operation must have associated control logic for fault stop/fault diagnosis. If a fault is detected, the logic controller stops the operation and announces the fault to the operator. Because of the causal dependencies in the operations of a machining system, the entire machining system is stopped by any fault, and the system must wait for a re-start command from the operator to begin again. The quality of the software programming of the PLC will influence in the stations performance, below, there are the 7 steps to be followed for a correct structure of a PLC program [16]:

1. Identification of external interfaces to the controller and the other equipment in the whole system.
2. Definition of the main signals exchanged between the control system and the rest of the plant.
3. Definition of all operator interactions, overrides and supervisory data.
4. Analysis of the control problem broken down from the top level into the logical partitions.
5. Definition of the required Function Blocks.
6. Definition of scan cycle time requirements for the different parts of the application.
7. Configuration of the system by defining resources, linking programs with physical inputs and
8. outputs and assigning programs and function blocks to tasks.

IEC 61131-3 helps you especially in the last steps 4 - 7, where the translation into software ccurs.Besides these 7 steps, there are some overall principles which should be used to optimize the structuring method. These principles are:

- Work purely in symbolic: no absolute addressing (this only in declaration part). Advantages: easy adaptation to changing environment, higher level of re- usability of code, fewer side effects.
- Program parts belonging to each other should be joined in the source code also.
- Do not use jumps. Advantages: higher transparency, higher level of re- usability, fewer side effects.
- Consistent naming of variables and function blocks increases transparency and overall readability.
- As the last stage before a new project or implementation in the software, we use a simulation device for the validation of its lo gic (Figure 10).

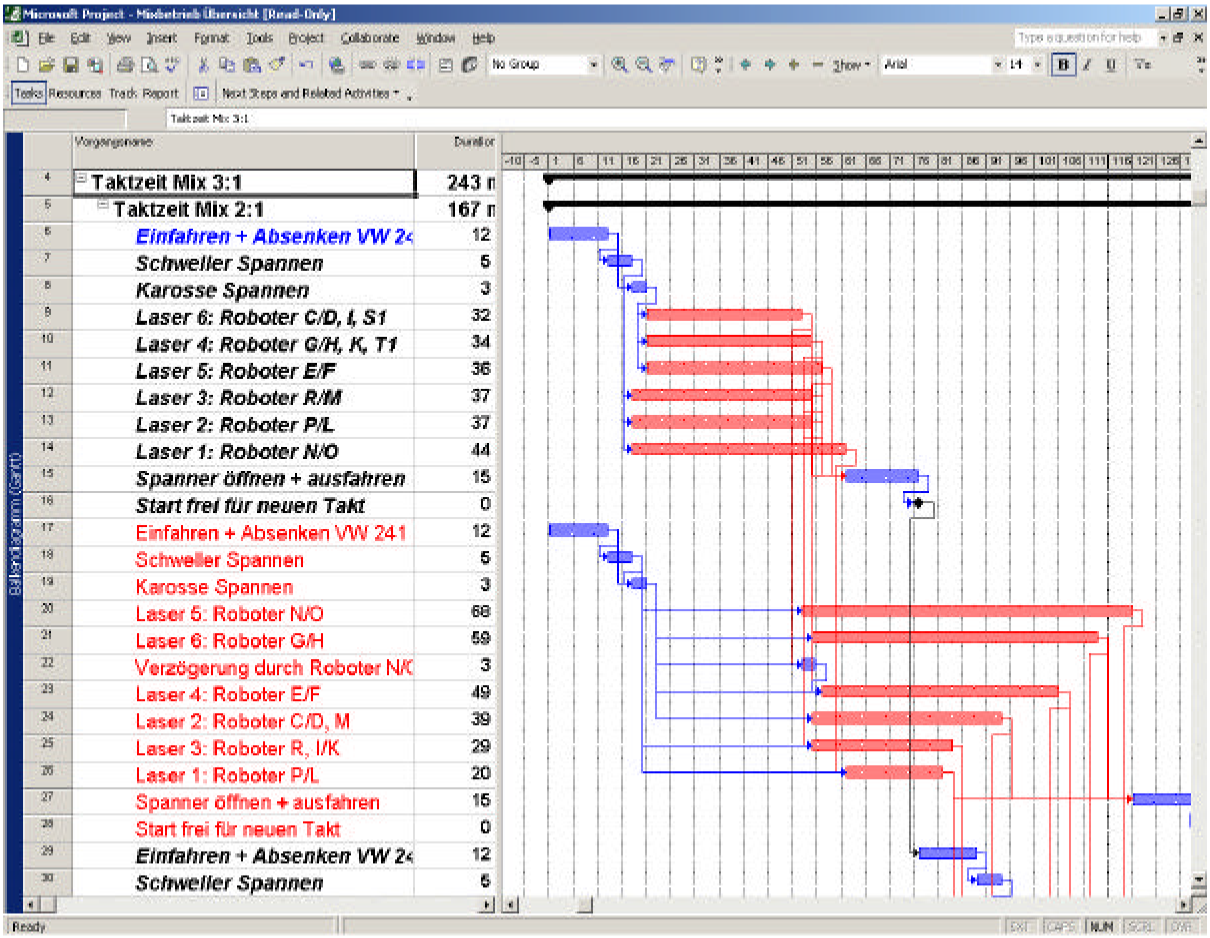

Figure 9: A time chart of one of the optimized operations with the help of the Microsoft Project

6. HMI (Man Machine Interface)

When we work with complex automatized systems as is the case of the LGG stations, it arises the need of creating an interface as to facilitate the work of the team in charge of the operation and maintenance of the system. To guarantee a good application of maintenance it is necessary to have a friendly interface (effective and ergonomic). The objective of a HMI is to permit the supervision and the command of the system operation and rapidly and precisely diagnose the flaws for a quick action, holding to the maximum the system availability. In architecture, the HMI receive data received from the PLC, translating in graphic signs for better visualization of the process. We have as HMI hardware of our LGG stations an industrial PC. Being based on Windows operational system, this powerful interface concentrates all the necessary tools for the command, the diagnose of flaws and for the edition of programs and parameters through the programming software's. For that, we have installed the following software's:

- Executable program of the diagnose and command screens (*"run time"*);
- Graphics Screens Editor;
- PLC program editor;
- Parameterization of the communication net editor;

The modus operandi of the HMI that we use for the interface in the LGG can be divided : in two, development and “run time” [17]:

Development Mode: This mode is, through the edition software’s it is possible to create or edit the graphical screens, i.e. where we elaborate a design that will be animated in the run time mode. It is also possible to develop and parameterize the configuration of the communication net and the PLC programming.

“Run Time” mode is the application in fact is used to make the navigation of the diagnose and command screens. In this mode, the HMI, through the communication net receives the information from all the system in real time supplied by the PLC through the communication net. In the “run time” mode or operational mode a project of screens of HMI should be coherent with the activities of the operators before the stations, for that the more urgent the information, related to the not nonprogrammed stops of the production that can jeopardize the availability of the station should be prioritized. Still in this mode, it should be predicted screens that will be able to permit to do operations in manual, or revert undesirable flaws that occurred. It is important to consider that to the construction of the architecture of the HMI screens all the modes considered before (Auto, manual and hand). We show in Fig. 11 and 12 below, some examples of screens in the mode “run time” used in the LGG stations.

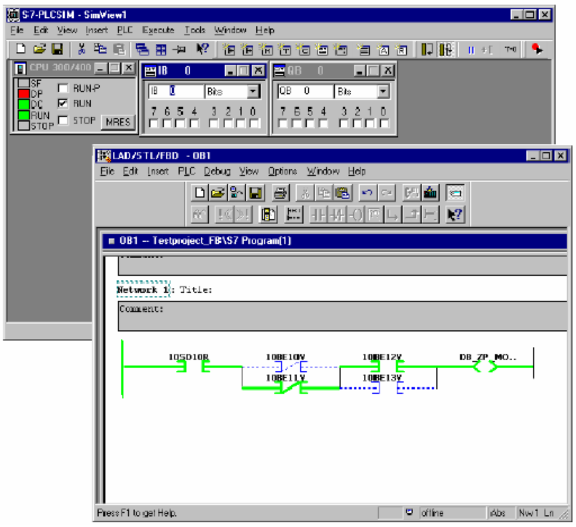

Figure 10: Simulation software employed for validation of the logic of PLC programming at its final phase, before the start-up. (S7-PLC SIM).

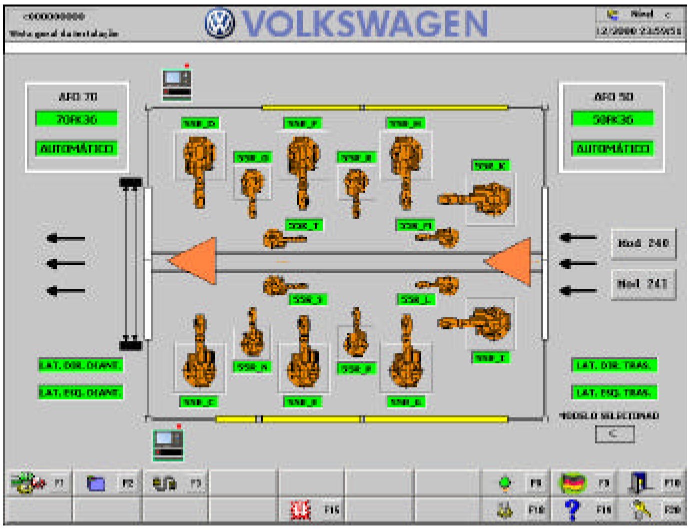

Figure 11 : Main screen where it is possible to have a general vision of the station and diagnoses - main flaws

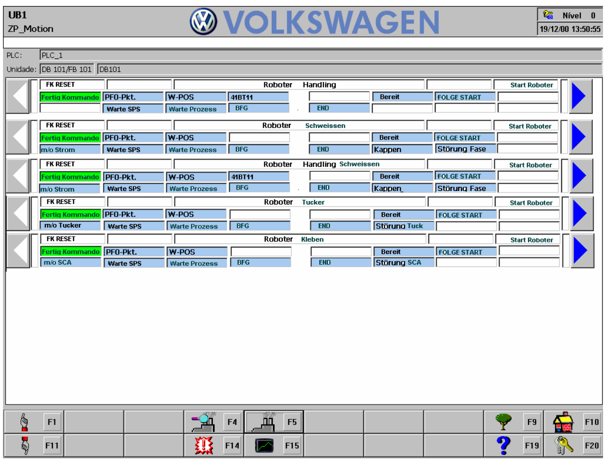

Figure 12 : Motion screen with executability for movements in manual and to verify the present position of the devices. It is also possible to diagnose flaws during movements.

7. CONCLUSIONS

In fact, the LASER technology applied in welding permitted to increase in many aspects the performance of the automotive bodies. But, the LASER technology, when applied in a geometry cell demands a high degree of quality in the automation process, mainly when we detach the main elements of its automation PLC and HMI) as well as its respective interfaces the other equipment of the installation. The quality of the automation infrastructure can guarantee for a complex cells as this, not only the quality of the weld application, but also a time of optimal cycle and availability coherent with the demands of an assembling line of vehicles of high cadence and performance.

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AUTOMAÇÃO DE CÉLULAS DE MANUFATURA PARA MONTAGEM DE CARROCERIAS AUTOMOTIVAS

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Resumo: *Nos últimos anos a competitividade trouxe para a indústria automotiva nacional, uma crescente necessidade de investimentos em automação na manufatura de automóveis demandando melhor qualidade, melhor volume de produção e flexibilidade. Este artigo tem como objetivo apresentar um caso de sucesso de inovações tecnológicas adotadas pela VW do Brasil em virtude do lançamento dos produtos Polo e Fox focando especialmente nas células de soldagem de carrocerias nas células de Solda LASER. As Principais inovações tecnológicas nessas, células é a introdução do feixe LASER de Nd-YAG no processo de junção, adotado especialmente para proporcionar uma melhor qualidade de acabamento na junção do teto e das laterais. O desenvolvimento desta nova célula tem permitido inovações no designes dos veículos, alem de permitir melhor controle de qualidade geométrica e metrológica durante todo o ciclo. Estas células operam com 16 robôs, um controlador e subsistemas de segurança, controle de qualidade, diagnóstico de falhas e comunicação, para operar sob condições de alta performance de aplicação de junção por LASER. Este artigo detalha a arquitetura desta célula, a qual é baseada em otimização de recursos assim como nos conceitos da manufatura enxuta, resultando numa melhoria da disponibilidade, operabilidade, baixo tempo de parada, maior flexibilidade e qualidade do produto. A descrição do controle da célula enfatiza o controlador principal (CLP) e as linguagens de programação padronizadas. A padronização permitiu não somente a melhoria da disponibilidade e economia dos recursos, mas também a detecção de falhas durante o processo produtivo.*

Palavras-chave: soldagem, automação, LASER, manufatura.