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Examining the Modular End of Line Control Unit Design Criteria for Vehicle Sliding Door System Track Profile

O. Kurtulus, C. Yavuz

Abstract**—**The end of the line controls of the finished products in the automotive industry is important. The control that has been conducted with the manual methods for the sliding doors tracks is not sufficient and faulty products cannot be identified. As a result, the customer has the faulty products. In the scope of this study, the design criteria of the PLC integrated modular end of line control unit has been examined, designed and manufactured to make the control of the 10 different track profile to 2 different vehicles with an objective to minimize the salvage costs by obtaining more sensitive, certain and accurate measurement results. In the study that started with literature and patent review, the design inputs have been specified, the technical concept has been developed, computer supported mechanic design, control system and automation design, design review and design improvement have been made. Laser analog sensors at high sensitivity, probes and modular blocks have been used in the unit. The measurement has been conducted in the system and it is observed that measurement results are more sensitive than the previous methods that we use.

Keywords**—**Control unit design, end of line, modular design, sliding door system.

I. Introduction

CUSTOMER expectations have risen during recent years in the automotive sector, therefore competition and time constraints have considerably increased [1]. Under these circumstances, system suppliers in the sector have been expected to generate more creative solutions and actualize these solutions within their extremely compact project calendars. In addition to meeting every test and performance expectation of the customer, such creative solutions need to provide time, cost and quality advantages to the customer so that those suppliers are preferred [2]. The main factors which affect data reliability are the accuracy and precision of the measurements that are performed on quality characteristics, the paramount clause of the product quality control system. One of the prerequisites of having an effective quality control system is to provide the reliability of the acquired data from measurement, in other words, the accuracy and precision of the measurement system [3].

An important step of the manufacturing process is the measurement and inspections which are performed on completed products at the end of the assembly line. End of line measurements determine not only the quality of the product but also the efficiency and stability of the manufacturing process [4]. The primary purpose in the end of line control units is to gain a reliable perception and sensitive measurements of more than one parameter. Hence, the main purposes of end of line control units also include identifying faulty products, reducing rejection rates, preventing faulty product shipments, and reducing the costs of poor quality.

The quality and measurement controls of automotive products are performed using various fixtures and devices.

Fixtures have direct effects on the manufacturing quality of the product, the efficiency and the cost [5]. Traditional inspection methods and manual fixtures cannot fulfill the measurement needs [6]. As a consequence, in recent years, producing quality products and fixture designs to minimize scrap costs have become more technological compared to previous years, computer aided designs and electronic based automation integrant control systems have become widespread [5].

In unit design, basic engineering principals should be taken into consideration. In the first fixture design process, the function requirements and constraints of these requirements should be determined [7]. The efficiency of the measurement results are dependent on the sensitivity of the equipment used, the precision and accuracy of the surface contact conditions and the visual sensory system [8].

Due to the lack in quality of our manually conducted measurement results, which we performed in outdated methods, the customers receive out of specification or poor performance products. As a result, high scrap costs and repair costs occur. Furthermore, the time spent on measurements and the number of measurement personnel is high. In order to solve these problems and execute an innovative technological design, a new design study was made.

In this study, by taking the purposes and criteria stated above into consideration, a PLC automation integrated modular end of line control unit design was made and the design criteria was examined. CATIA software was employed to make the design. At the end of the design, trial measurements were performed and they were compared with measurement results done using outdated methods.

II. Sliding Doors

Sliding doors are type of doors in which the opening-closing process is achieved by horizontal mechanisms that slide on tracks in vehicles [2]. They are usually used in light

O. Kurtulus and C. Yavuz are with Rollmech Automotive San. ve Tic. A.S., Bursa, 16140 Turkey (Phone: +90 549 800 04 75, +90 549 800 06 11; fax: +90 224 243 87 67; e-mail: orhan.kurtulus@rollmech.com, cuneyt.yavuz@rollmech.com).

commercial vehicles. The use of sliding doors in vehicles provides larger loading and usage area, the opportunity to work in confined spaces and ease of use.

Fig. 1 Light Commercial Vehicle with Sliding Door Mechanism

In passenger cars, hinge anchored doors are commonly used. Yet, as a result of a changing and developing urban life, sliding door usage becomes more common especially in vehicle groups which target extended families with children.

Fig. 2 Passenger Car with Sliding Door Mechanism

Sliding doors need to have a long lifetime and effort values related to being used whether in passenger or commercial vehicle, a customer's special request. They have the requirements of having an opening and closing strength in 250 000 spin, not being deformed with 15000 N weight, preserving its effort values under -40° C and +80° C climatic conditions.

Sliding doors work by means of a mechanism, which has a three carrying roller system. These three mechanisms are agents of a roller mechanism with a carrying purpose or guiding purpose mechanism as well as being flexible agents in each vehicle.

III. Sliding Door Tracks

Sliding door tracks are components in which roller systems move. Track forms are designed in accordance with vehicle forms. In addition, tracks are formed by envisioning the distance status between the door and the body when the door is fully open.

Main functions of tracks;

- Determining the door kinematic by guiding the course of roller systems.
- Sustaining the vehicle door weight. Therefore, track sections and sheet thickness vary in accordance with the door of the vehicle.
- Determining the opening and closing kinetics of the door. Door kinematic is determined in the form of a track profile.

Moreover, tracks are optionally applied with styling in order to achieve visuality in some projects. The aim here is to bring aesthetic visuality to the vehicle. Besides, tracks provide montage space for vehicles to put trims and exterior pieces.

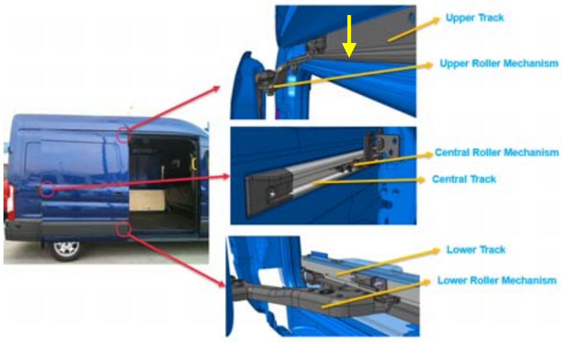

Fig. 3 Mechanisms and Tracks of Sliding Door

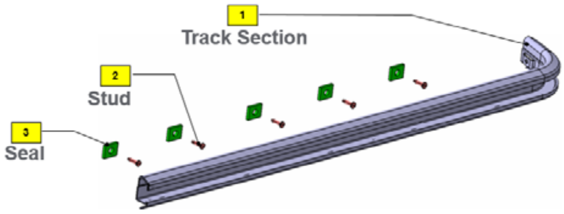

Fig. 4 Sliding Door Track Profiles and Components

A track form does not always provide accurate measurement results in standard fixtures since it has a complex structure. This is because sufficient measuring space is not provided in every point of the track form. Therefore, in order to obtain more sensitive, necessary measurements, visually controlled measurement systems should be used.

Measurement constrictions in the track section cause the door to jam, not to open and work with high effort. Measurement deviations in a track roller surface cause the door to have a larger gap, therefore work loudly. Loud working door cause the end user to be dissatisfied and to complain. Measurement failures, which could occur in track form cause the door to lock and scrape other parts on the body in the opening-closing process by affecting the door's opening kinematic. Surface failures such as bumps, thickening and fluctuation cause functional and visual failures on the vehicle. Therefore, track measurement and controls should be practiced by a sensitive and technological control system under a high level of discipline

IV. Manufacturing Process of Sliding Door tracks

By passing a roll-form line, the work piece with a shape similar to a sheet is executed as the first form of the track.

When the profile formed in Roll-form line reaches its desired height, it is cut by an automatic cutting machine.

Profiles cut in the desired height are twisted in a bending line in order to form the track's curve section. After this operation, there is another cutting process in the cutting towers for the product to come to its final height.

Fig. 5 Forming Sheet Work Piece in Roll-form Line

Fig. 6 Stretch Bending Operation

The boiling of the drilling and studding screws process is applied to the track profiles after the stretch bending and cutting operation.

V. Track Measurement Methods in Current Status

The sliding door system's tracks, punctual positions after manufacturing, dimensional measurements, section, form and critical characteristics should be controlled.

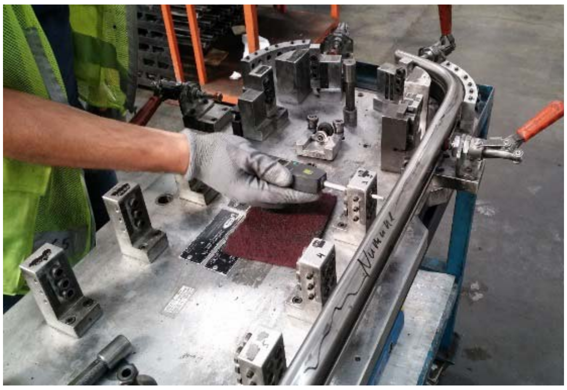

Fig. 7 Track Form Measurement by Comparator

As soon as receiving the available manual track measurement and controls, comparators should be done in CMM devices. Sufficient sensitivity cannot be fulfilled in these measurements. Distortion in the tracks, partial bumps, and critical characteristics cannot be measured in the desired sensitivity. In particular, the track profile in the sword section cannot perform tailing control. Since different equipment is used in each measurement, the time spent and the number of working personnel is high. Furthermore, since the measurements are conducted from mass production, faulty products are determined by measurement frequency. Hence, it is an issue that faulty products could occur among products, which are out of the measurement range.

Fig. 8 Control of Roller Circulation Area between Master and Track

In the measurement depicted in Fig. 8, it is being checked manually whether the roller is stuck in the track or not. Since this method does not provide a sensitive solution, there can be jamming problems in the rollers after assembly.

After the stretch bending operation, the profile section is inspected in the fixture. First of all, the track is manually placed on the fixture. Three clamps are locked respectively. Resetting of the 75 mm comparator is performed. This comparator takes measurements from six different comparator housings in order to control the radial distortion area. Here the measurement value is accepted as ±1.00 mm. After these processes, measurements continue with a 35 mm comparator. To control certain sections in the track profile line, measurements are made from 30 different comparator housings. Here the measurement value is accepted as ±1.00 mm. Average measurement duration in this portion is 148 seconds. Measurement results are manually written in the operation registration form during the measurements. Writing the results to the operation papers lasts 215 seconds on average. Thus, the total time spent for recording these measurements and measurement results is 363 seconds on average.

Position of the stud bolts welded on the profile is inspected in the fixture after the operation. The track is manually placed on the fixture and locked with four clamps. After resetting the 75 mm comparator, measurements are taken from six different comparator housings for the inspection of the reference surfaces. Here the measurement value is accepted as ± 0.5 mm. The time spent for the measurements is 95 seconds while writing the measurement results to the operation registration form is 145 seconds, thus the total processing time is calculated as 240 seconds.

Fig. 9 Comparator Housings Measured After Stretch Bending

Fig. 10 Fixture Measured After the Stud Welding

VI. Modular End of Line Control Unit Design and New Measurement Control System

While a separate fixture and measurement apparatus were used for each track in the previous method, measurement and control of 10 different tracks of two vehicles can be performed in a single unit in the new design. Thanks to the new unit, four different tracks of the two models as right and left with short axle distance and middle axle distance, which belong to the first vehicle. Six different tracks of the three models as right and left with short axle distance, middle axle distance and extra-long axle distance which belong to the second vehicle can be measured precisely and accurately.

As will be seen in Fig. 12, track geometries are also designed different according to the vehicle models. The differences, which are regarded as small create great differences in terms of function and installation in the vehicle components. Thus, measurement of these differences and precision of the measurements are extremely important.

Fig. 11 First Vehicle in which Track Measurement is performed

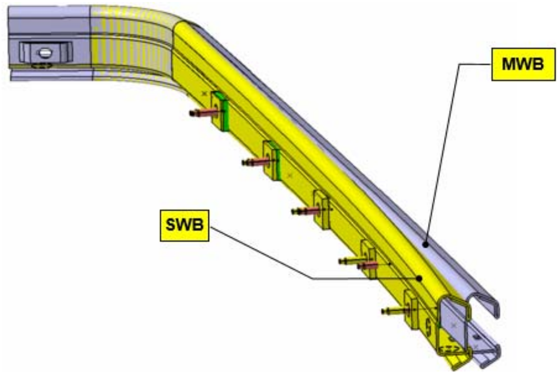

Fig. 12 Difference of the Tracks Belonging to the First Vehicle

Fig. 13 Second Vehicle in which Track Measurement is performed

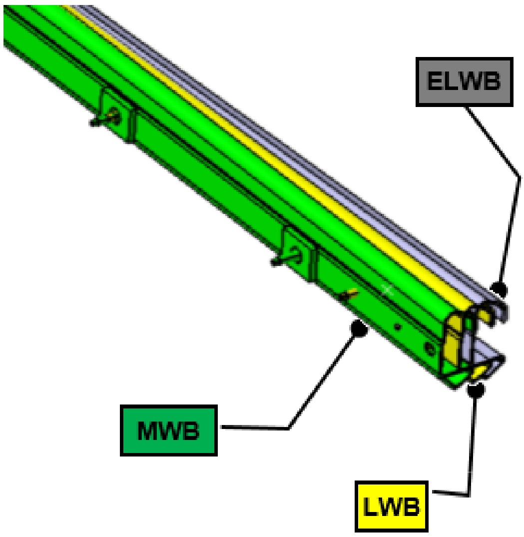

Fig. 14 Difference of the Tracks Belonging to the Second Vehicle

There are five stud bolts on the track and the position of these studs is different from each other. In order to differentiate the tracks, mechanical poka-yoke design and application was performed in the unit. Through the slot holes opened in the blocks, positions of the stud bolts and connection points of the track are designated. Moreover, the block surfaces were designed in a manner to simulate the vehicle body form. Thereby, the track fixed to the unit will seem as if it is mounted on the vehicle. When problems such as perpendicularity and measurement position occur in the stud bolts, welded stud bolts are not placed on the blocks and are rejected, thus product shipment is prevented in this stage. Since there is the option of dismounting in the blocks, with the use of different blocks in each track, inspection of ten different tracks can be made by means of modular blocks in a single unit.

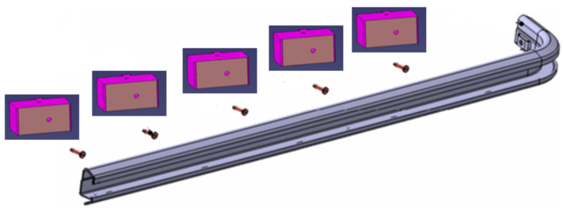

Fig. 15 Track, Stud Bolts and Blocks

A. Distortion Inspection of the Track

Laser analog sensors were used for inspecting the distortions in the contact points of the track on the vehicle while probes were used for inspecting the twisting of the track. PLC algorithm was written for these devices and the system was integrated to the PLC automation.

B. Inspection of Deformation in the Sharp Section of the Track

This inspection is made with five probes. Schematically probes shown as P1...P5 inspect the deformation in the track profile according to the ’’0’’ tolerance point. According to the probe data measurements sent to PLC, they are calculated and the approval or rejection decision can be given according to the tolerance range accepted by the vehicle. Thus, standardization of the track profiles in tolerance with specific limits is provided.

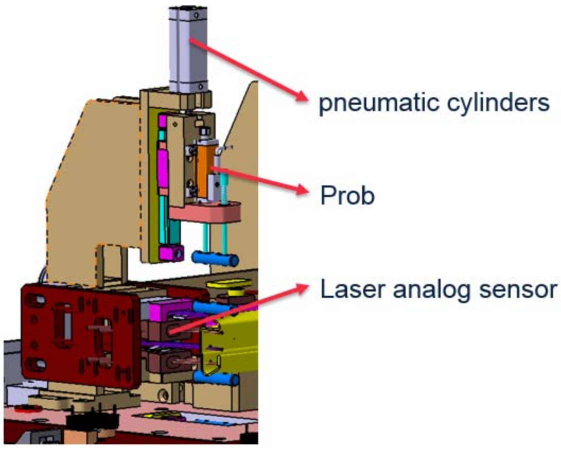

Fig. 16 Laser Analog Sensor, Prob, Pneumatic Cylinders

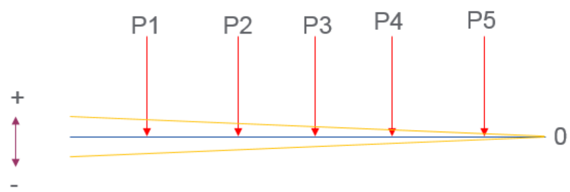

Fig. 17 Schematic Representation of the Probes

C. Measurement of the Profile Section

The profile section is measured by laser from four points along the line. The measurements which were manually made with comparators previously are automated, and accepted or rejected with PLC confirmation algorithm. Measurements are made from certain points in the profile section and whether these measurements are within the tolerance range or not are transferred to PLC. The profile is inspected with this measurement method which also provides the information about the extent of distortion in the respective profile and the ones out of these standards are rejected. Thus, the risk of delivering defected products is eliminated.

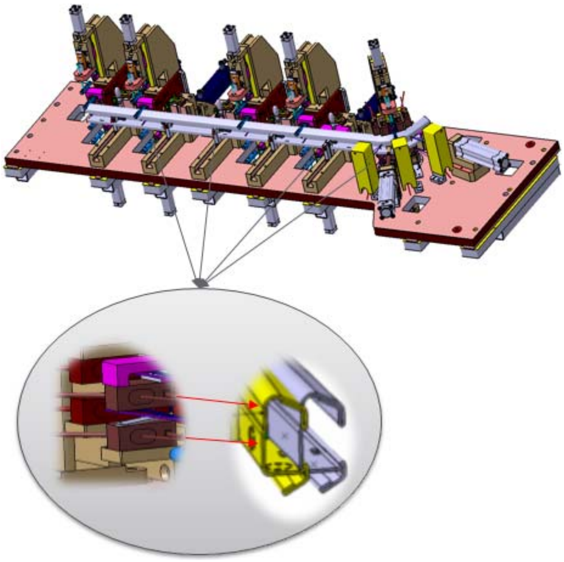

Fig. 18 Profile Section and Laser Measurement

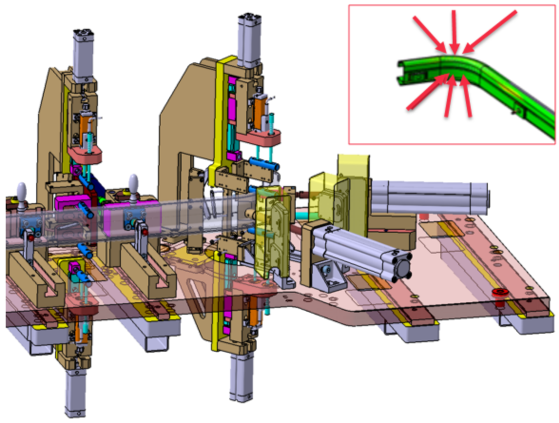

Fig. 19 Bent Area and Measurement Method

D. Track Radial Area Measurement

In this measurement, the inspection of whether the distortion which may occur due to the production in the radial area of the track are within the acceptable tolerance range or not is made. The distortions which are within a specific tolerance range in the radial area controlled with laser sensors are accepted; the ones which are out of a specific tolerance range are rejected. Lasers controlling the radial area from six points measure the distance and determine the ones within or out of a specific tolerance range by means of PLC.

VII. Comparison between the Results of the Measurements Made with the Previous Method and Measurements Made in New Design Control Unit

The operations were performed manually in the previous methods are the measurements which require more time, depend on precision of the operator, require more operators and fail in providing sufficient precision. The new design has provided us with precise and accurate measurement results in a shorter time and by using fewer operators.

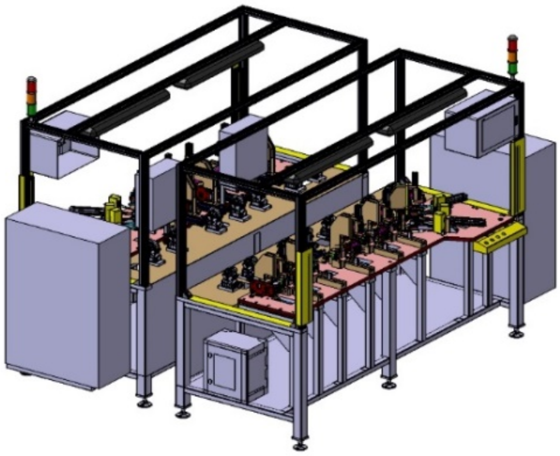

Fig. 20 Modular End of Line Control Unit

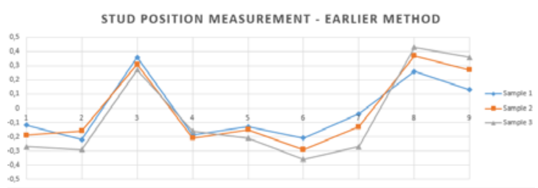

Fig. 21 Stud Position Measurement- Earlier Method

Earlier Method	1	2	3	4	5	6	7	8	9
Sample 1	-0,12	-0,22	0,36	-0,19	-0,13	-0,21	-0,04	0,26	0,13
Sample 2	-0,19	-0,16	0,31	-0,21	-0,15	-0,29	-0,13	0,37	0,27
Sample 3	-0,27	-0,29	0,27	-0,16	-0,21	-0,36	-0,27	0,43	0,36

Fig. 22 Stud Position Measurement Results-Earlier Method

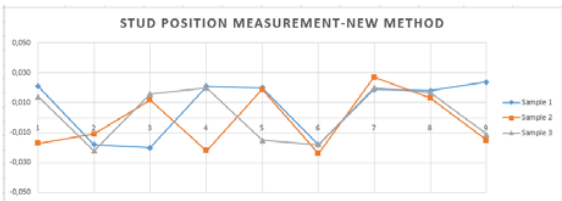

Fig. 23 Stud Position Measurement- New Method

New Method	1	2	3	4	5	6	7	8	9
Sample 1	0,021	-0,018	-0,020	0,021	0,020	-0,018	0,019	0,018	0,024
Sample 2	-0,017	-0,011	0,012	-0,022	0,019	-0,024	0,027	0,013	-0,015
Sample 3	0,014	-0,022	0,016	0,020	-0,015	-0,018	0,020	0,017	-0,011

Fig. 24 Stud Position Measurement Results- New Method

Measurement results with the previous and new methods are compared in the graphs. As will be understood from the measurement results, the measurement results obtained in the modular unit of the new design are more precise.

VIII. Discussion

According to the measurement results, more precise and accurate measurements are observed to have been made in the PLC automation integrated modular end of line control unit. In the new design, a precision of 0.03 mm was achieved on average. While the time spent for a single measurement parameter is between 4-6 minutes using the previous methods, this time was reduced to 28 seconds in the modular unit. Marking was made to the tracks inspected with the new method. Thanks to this marking number, track measurement results are recorded by PLC and monitoring is provided. Moreover, by performing the measurement of ten different tracks of two vehicles, the numbers of equipment used was reduced compared to the previous method and the operator effect was removed by automating the measurements.

IX. Conclusion

The fact that the customer expectations are met by allowing the ideas which provide the sector with a different viewpoint to be applicable with the developing technology provides the brands to be preferred. The functionality and quality of the components used in the automotive sector is important, thus, the measurement and inspection of these parameters is also quite important. This is because the measurement and control system determines the quality of the product, process and quality process efficiency. Today, to obtain more precise and accurate measurements in a shorter time electronic based and visual control systems are gradually becoming widespread.

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