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Automotive body-in-white dimensional stability through pre-control application in the subassembly process

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ABSTRACT

Purpose: This paper presents a case study and results of a pre-control method that allows for detecting subassemblies variations with low investments using a methodology that search an improvement in quality of automotive body in white assemblies joining processes through dimensional control.

Design/methodology/approach: Its main contribution is the statement of pre-control method to manage the weld assembly process since the early step of the project implementation just up to the production phase. However the pre-control method didn't substitute any other dimensional control, the scope here was to demonstrate that such alternative method offers a reliable in control process of the dimensional changes and their repeatability, as it only complement the current methods used in the automotive industry. It is emphasized here the dimensional control as well as some process quality tools.

Findings: It is showed the results and impact of a pre-control method in the weld assembly process, highlighting dimensional stability improvements and annual cost reduction through reducing rework hours and scrap parts quantity.

Practical implications: The pre-control, revealed as a simplified tool application and can be used by the production operators with low investment cost and operation.

Originality/value: The application the pre-control method is more efficient in subassemblies manufactured from manual process or that allows greater interaction of the production operator.

Keywords: Quality control; Automotive; Body in white; Welding; Assembly; Pre-control; Manufacturing

1. Introduction

The worldwide market opening and automotive production capacity increment stimulate the automotive plants competitiveness. For the automotive industry the quality is reflected through the customers' satisfaction in relation to the products and offered services. So that this occurs, each area, departments and activities inside of the automotive industry must have the same culture to satisfy the internal customers generating parts and components with quality.

The body shop area, responsible for the body-in-white assembly and its subassemblies, has a special responsibility to guarantee final dimensional geometry of the automobile, what it makes possible the final assembly of the mechanic, trim, comfort and safety components with world wide class of quality. The great operations diversity in the body shop process becomes the productive system very complex for the evaluation and quality control and dimensional control [11]. The continuous search for methods and tools of quality control applied in a suitable way helps to guarantee more steady processes, inside of the specifications, reducing variations and losses in the productive process. Through the concepts demonstration, application and results of a pre-control method applied to the dimensional of car body subassemblies, it is possible to identify the variations of the body-in-white assembly process with low investment, resulting in the dimensional stability.

2. Pre-control and manufacture process

The pre-control was developed at the beginning of 1950 by Satterhwaite [12] and a group formed by himself, C. W. Carter, and W. R. Purcell and Dorian Shainin [6, 7]. The pre-control method was further developed by D. Shainin and P. Shainin, S. Purcal and P. Carter as a simple and fast method if compared to the Shewhart control graphs [1, 3, 8, 10, 13-15, 17]. This method gained popularity in 1960 middle when it virtually disappeared, according to Bhote [2]. Reappearing in 1980, the pre-control application comes growing [20]. The same as the control graphs, the pre-control uses a specification band division to adopt regions green, yellow and red, that immediate reply to the operator or another responsible person for the process, if it is according to the specifications. After Vandergrift [18, 19], simulations had been used to determine the validity of the pre-control, highlighting its basic prerequisite and the manufacture processes applicability.

The pre-control demonstration is adequate to keep the process inside the specified limits when the variation and the displacement of the average are in specify conditions inside of the process control. The main objective of the pre-control is to determine the process pre-qualification. After the process is pre-qualified and ready to initiate, it is enough only to the assembly one piece to determine if the process is under “control”, being unnecessary complex graphs or calculations as they occur in the control statistical. The pre-control estimates that already exists a previous knowledge, or that this knowledge can quickly be developed to adjust to the variations or displacement if a problem is detected.

3. Process capability impacts pre-control

A process capability Cpk equals to 1.0 means that the tolerance is equal the 6. Sigma and the process average coincides with the tolerance average, where sigma is the standard deviation [15, 18, 19]. As example, assuming a normal distribution, 86% of the readings can be inside of the green zone of pre-control and 7% in each yellow zone, corresponding to 14 readings, as demonstrated in Fig. 1. Some examples illustrate the application of pre-control for one side tolerance processes as concentricity dimensions (Fig. 2). Many authors associate the impacts of the process capability in the effectiveness to detect alteration in the average and changes of variation. When pre-control was developed, the capabilities of the process (Cp) even so necessary for a process with centered distribution inside of the tolerance limits was in at least in 2.0. Researches had later shown that a Cp of 1.33 or above is enough to optimize the characteristics of detention of the pre-control. The pre-control detects more quickly changes in the average deviation than a graphical of control at low Cp from 1.0 to 1.2. The original formulation for classical pre-control is described by Shainin, Shainin [13] and Traver [16]. A two-stage improvement is discussed by Salvia [9] and a third, different approach was suggested by Gurska and Heaphy [4].

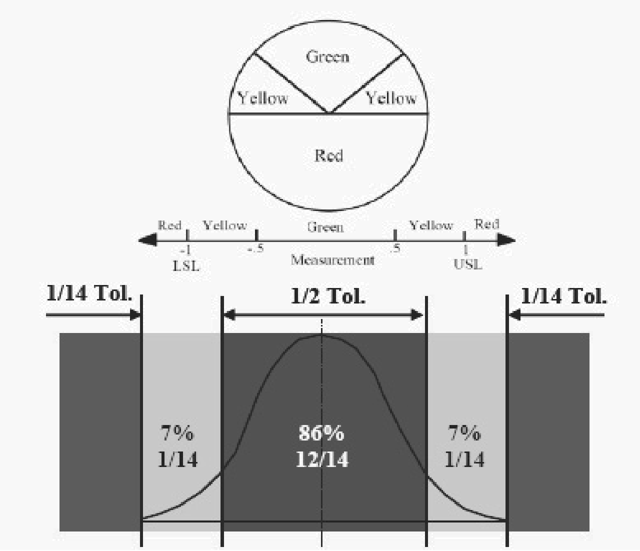

Fig. 1. Tolerance percentage in pre-control zone

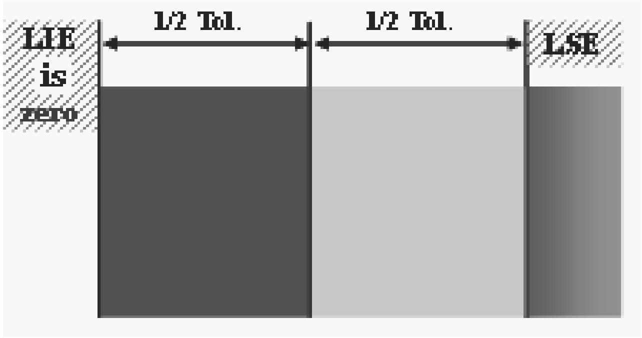

Fig. 2. One sided tolerance Pre-control zone

4. Sampling interval

For the interval definition between samples it is recommended, after Urdhwareshe [17], that the period of time between the adjustments should be divided by six samples. Table 1 presents the frequency definition.

Table 1.
Pre-control sampling interval example

Average time between process adjustment	Sampling Interval for parts
8 Hours	Every 80 minutes
4 Hours	Every 40 minutes
2 Hours	Every 20 minutes
1 Hours	Every 10 minutes

5. Pre-control pratical application

The pre-control uses a pre-qualify process procedure to determine if it is ready for the production. The pre-qualification occurs when five consecutive parts or sets reach the green zone. The process is interrupted and adjusted when two parts or sets reach zones yellow, in the same or into opposing zones. The greens' counting is restated after two parts or sets in yellow zones occur. After Shainin & Shainin [13], if the amount of parts located in the red zone is bigger or equal 3% of all the produced parts, then the probability of having two consecutive yellows or a red enough great is compared with the probability to occur five consecutive greens. Once the process passes for the pre-qualification, the distribution of the process practically is assured inside of the specified limits and the standard deviation is very next to being centered. In this way, the pre-control does not operate based on in the normal distribution, but in the distribution percentage in the red and yellow zones, being the main objective, to prevent defects instead of detecting changes in the variation and deviations. If five consecutive parts are in the green zone, the adjustment is OK, Fig. 3, and the process is ready to initiate. If a yellow will be detected, it must restart the counting. If two consecutive yellows are detected, it is necessary adjusting the process. If a red happen, it stops and adjusts the process.

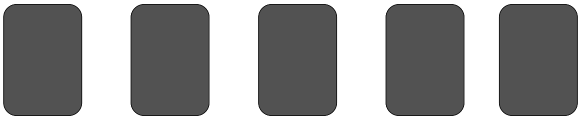

Fig. 3. Pre-control qualify approval criteria

6. Pre-control at the manufacturing plant

When regarding two samples A and B of two consecutive parts, if the sample A is in the green zone, then the process continues. If one is in the yellow zone and to another one in the green then it continues also. If both samples (A and B) are in the yellow zone of the same side, the process has to be adjusted. If the samples are in the yellow zone, however opposing, you should call help because it may require a process revision. If one of the samples is in the red zone, then you should adjust the process. When this last case happens, parts produced from last sample must be inspected, through a process tracking (see Fig. 4).

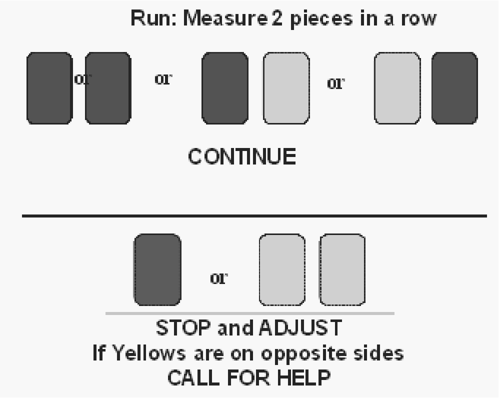

Fig. 4. Approval and rejection criteria

7. Pre-control methodology & assembly line

7.1. Standards parts preparation

The standard parts process of preparation (master panel) has the objective to use the parts in the adjustment of the assembly fixtures, as it is the case of the calibration of the process or the analysis of repeatability, in the validation and the productive pre-control of the process. The created standard parts from the inspection fixture must be applied in the calibration process. In the other hands, standard parts created from the assembly fixture must be used for ends of productive process validation and pre-control. To each step of the assembly, the drill holes must be executed in the surfaces in the intersection of the parts next to the localization bolts, in order to guarantee the control of variation in all the directions. The minimum of two holes for part is recommended. The assembly sequence must be followed in agreement the sequence of assembly in the assembly fixture. The parts must be drilled (witness hole process - witness panel), with verification hole of 4.0 mm of diameter, that they are used to indicate, through its alignments, the relative positioning among the parts of the assembly. To the ending of the drill operation, it is recommended to remove the burrs to prevent interferences during the verifications. Reinstall the parts in the fixture to verify the repeatability and alignment of holes. The parts standard must be riveted together in adjacent place the localization of the weld points. The standard parts preparation must have the following procedure for productive process validation or pre-control ends: Install the parts in the assembly fixture, to close to open the clamps three times to minimize eventual parts deformations. Drill the parts with the same criterion mentioned for the standard parts applied the process calibration. Open the cramps, remove the parts and the burrs of the holes. Reinstall the parts and close the clamps again, repeating three times to verify the alignment of the hole. It is recommended the elpo painting to the parts to prevent oxidation during the periodic use in the process.

7.2. Body assembly process calibration

The body calibration process uses a set mounted in the inspection device to carry through the adjustments in the assembly fixture. The process must be carried through in the inverse order of the assembly sequence, from the final operation of the process to the first operation. The steps for accomplishment of the process are: Remove the rivets in each station of assembly so that only the parts that are been assembled in that station can be located untied in the device. The verification holes alignments of the standard parts show that the localization points of the assembly fixture are in agreement the localization points of the inspection device. Alignments with differences of up to 0.5 mm are considered OK. Values between 0.5 and 1.0 mm are OK, however with comment. For bigger values of 1.0 mm it is not good, the discrepancy must be investigated. After to carry out the adjustments to verify the alignment of the hole; remove the standard parts of the assembly fixture and reinstall them to verify the repeatability again. After all the operations to have been inspected for the calibration process, weld the standard parts in agreement to assembly sequence. The change in the allowed difference of alignment is of 0.5 mm. Holes that with diameter of the 3.0 mm must continue with the same dimension. The diameter obtained through the standard parts verification of the alignment of the hole must after be repeated after opening and closing of the setting clamps. The process must be registered in the calibration fixture register report.

7.3. Body assembly process validation

The validation process of assembly must use the standard parts (witness to master panel), prepared through the procedure of standard parts preparation. It is recommended to execute the process validation before and after the welding, and the weld machine must be set "cold weld". After the conclusion of the process, it must be finally proceeded the weld, setting the machine on "hot weld", finishing the assembly and confirming the process. The validation process is similar to the calibration process except for the fact that it concentrates in the aspect of variation repeatability, while the process calibration takes in account the coordinates of the inspection fixture. The process validation only answers the question "What is the fixture repeatability behavior before and after the weld assembly?" This question must continuously be answered during the life of the process. The procedure follows the following steps: Locate the parts in the assembly fixture, close the clamps and execute the holes alignments verification using the gauge. After finish the verification, open the clamps and to remove the parts. Repeat the process ten times and after concluded, register in the proper form. After that, close the clamps again, and apply the "cold weld" to observe eventual parts movements. Repeat the process five times with "cold weld". If it will be necessary, preparer new standard parts in case the fixture is not approved until this stage of the test. Even so, as mentioned for Urdhwareshe [17], the number of five samples used for the process validation is adequate and is associated to the process capability, Cpk, the value used in the method, ten samples, considered that each subgroup has six verification points on average, what it becomes the average assembly Cpk lowest, compared only to one verification point, what it justifies the definition of ten samples for qualification.

7.4. Pre-control in the productive process and its contribution

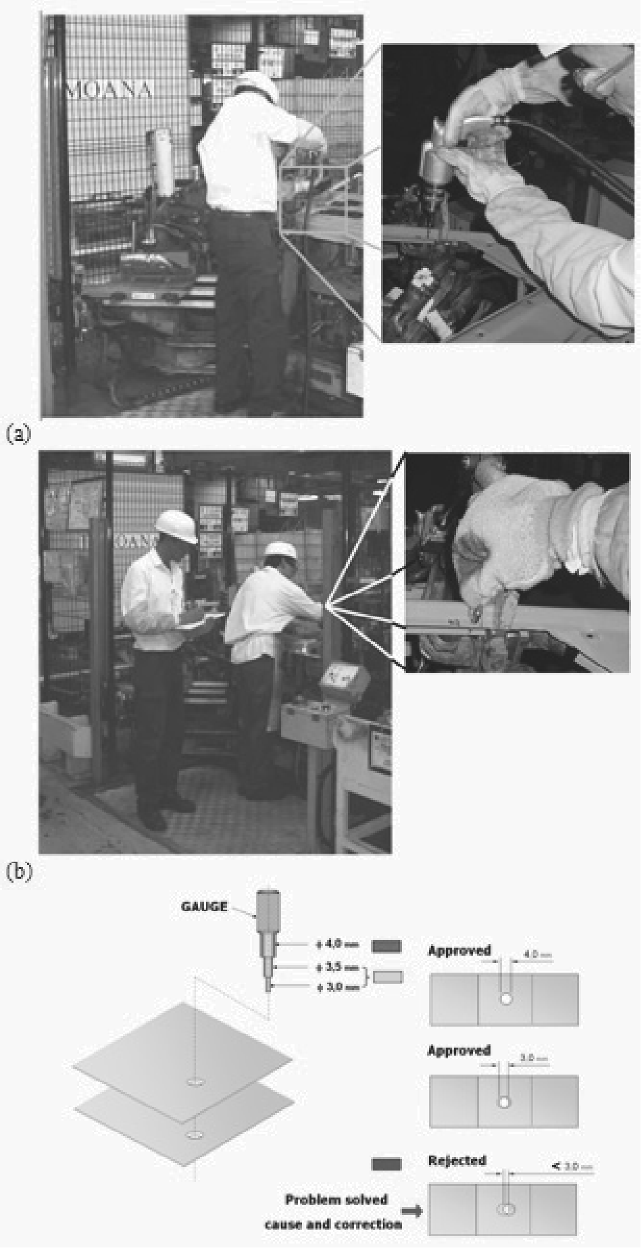

Fig. 5. Tomoana method: (a) drilling and standard part preparation. (b) Process pre-control (c) alignment approval and rejection criteria

As a problem solving tool the pre-control process applied to the assembly process is considered a reverse process. The parts can be located in the assembly fixture, drilled to get the alignment holes and taken until the inspection fixture. For the positioning of the parts in the inspection fixture, we can verify discrepancies and the corrections necessity. If the holes are lined up, this indicates that the localization points of the inspection fixture are in the same position of the inspection device. If the holes are not lined up, then the localization points are dislocated. The approval alignment criteria for the hole considers approved hole that can be uses used the gauge of 4.0 mm of diameter. Holes where the gauge of 3.5 mm is used are approved. Already holes where the gauge of 3.0 mm is used are approved, however they must be registered in the documentation forms. The variation can become a future problem or during the production process, therefore the gotten information must be used for the process of solution of problems. Holes lined up with inferior dimensions that they do not make possible to use the 3.0 mm gauge are rejected, (as shown in Fig. 5) having to be adjusted the place of the points of assembly.

For practical application of the pre-control method in the body-in-white subassembly process was chosen a company with a vehicle assembly plant. Tomoana, as it was baptized in the studied automobile company, it is a practical method of application of pre-control. "Tomoana" is a Japanese originated word where the term "tomo" means "coincident" and "ana" means hole. The adopted criteria to determine which subassemblies must pass through the "Tomoana" method where decided for exported items, such as hang-on like hood, deck lid, tail gate, doors, or either employed for subassemblies that present high number of internal customers claim, of the next stages of the assembly of vehicles chain and causes difficulty of components assembly due the dimensional variations in the body-in-white assembly process. Juran [5] mentioned that the pre-control is more adequate to the initial stages of the process where it knows the process capability and in these chosen subassemblies already is executed the statistical control. For each subassembly chosen for application of the pre-control, "tomoana", the verification points are identified as show in the Fig. 6.

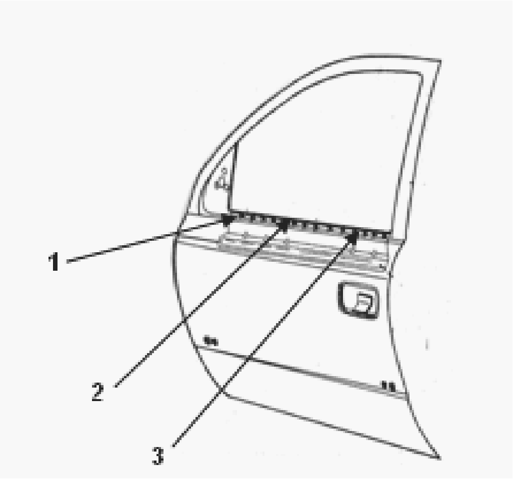

Fig. 6. The door panel tomoana's inspection on 3 points

To implement the method "tomoana" it is necessary to have a trained multi-functional team in its procedure and criteria, with representatives of the production areas, maintenance, quality and production engineering. Besides training, some infrastructure resources are necessary as quality standard boards, register forms, to record the repeatability studies, the initial process certification and the verification "gauge". The manufacture of special gauge is necessary for the "tomoana" processes considered by the pre-control. They must be manufactured with steel SAE 1050, quenched and tempered, as showed in Fig. 7.

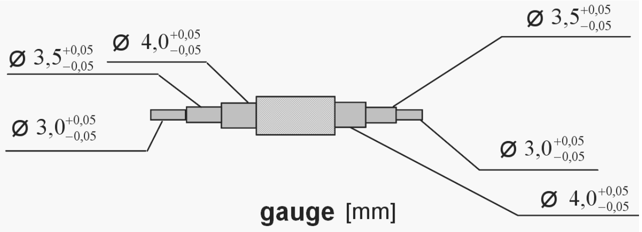

Fig. 7. Special tomoana's gauge

The considered tomoana method already is implemented in more 50 subassemblies in the studied company. The Fig. 8 shows the amount of subgroups that allow the implementation of the daily pre-control process. After Bhote [2], the pre-control is an easy learning and application process and the method can be spread out quickly. Tomoana, through pre-control, becomes the process body-in-white assembly process more robust.

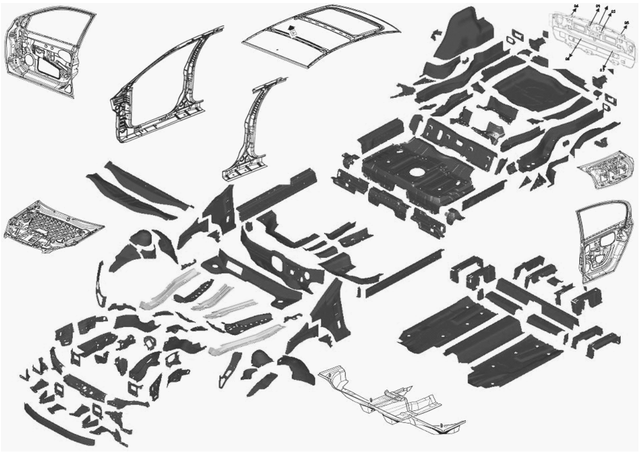

Fig. 8. Auto body-in-white subassemblies split

For the pre-control method study was used the following subassemblies: internal panel of the door opening, left and right side through the analysis and results validation. Each subassembly has a statistical control of the through daily measurements, one time per production shift, through inspection fixtures and dimensional electronic data collectors. To calculate the capability of sample for 10 parts, it should be employed the following equation, after QS900:

$$Cp = \frac{2.(0.9729)}{6.\left(\dfrac{\text{Range}}{3.078}\right)} \qquad (1)$$

Applying the equation 1 for the shown subassembly the process capability is 1.16, what is adequate to the pre-control application. Through the considered method of pre-control, called tomoana, applied in the subassembly process, we could get greater dimensional stability of body-in-white, through the variations reduction shown in the statistical control graphs. The method allows reaching the 95% objective at 6 Sigma, which demonstrates that 95% of the measurement points are varying inside the six sigma range. Besides the dimensional stability, there were great reductions in the number of assembly problems reported for the final assembly stages, which was caused by body-in-white subassembly process variations. Fig. 9 presents a dimensional report for the BIW subassembly quality control of an internal front side panel.

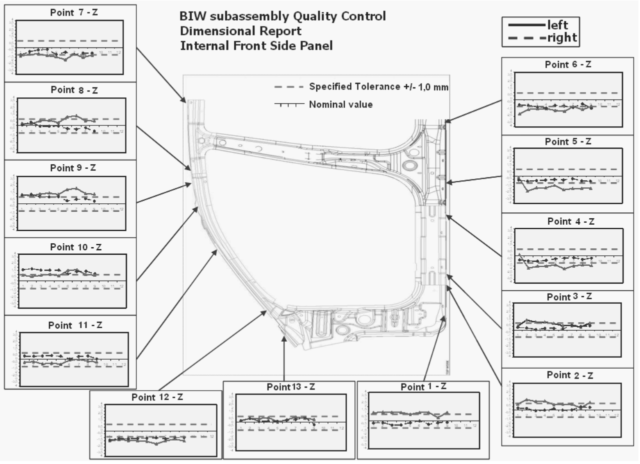

Fig. 9. Dimensional report for the BIW subassembly quality control of an internal front side panel

The Fig. 10 shows the reduction in the number of units with discrepancies in the further assembly or in another component due the dimensional variations. It is possible to notice that after the implementation of the method, the occurrences had reduced drastically. Another important aspect is also the number of claim proceeding from external customers, which receive the subassemblies to assembly vehicles in other countries. For these cases, the importance of guaranteeing a robust process are still bigger, because many times such customers do not have structure, or even though the parts that allow rework, what it can reject all parts.

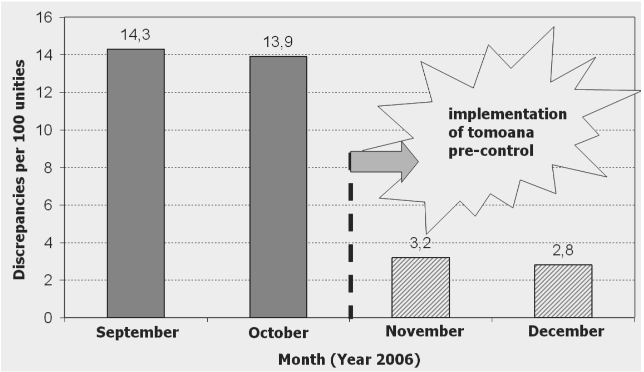

Fig. 10. Internal customer dimensional discrepancies chart - next assemblies

The Fig. 11 shows the reduction in the number of occurrences of parts with dimensional problems from external customers, due subassemblies exportation. Taking in account all the quality benefits that the "tomoana" method provides is possible to convert such results for an economic evaluation. Through the reduction of the reworks number of defective subassemblies, or the cost of scrapping those that do not make possible rework, it is possible to compare the economic results of the pre-control system implementation, tomoana, in the process body-in-white subassemblies. The Fig. 12 and 13 demonstrate the reduction in the number of hours consumed for month for the subassemblies rework and the number of scrap assemblies during the process

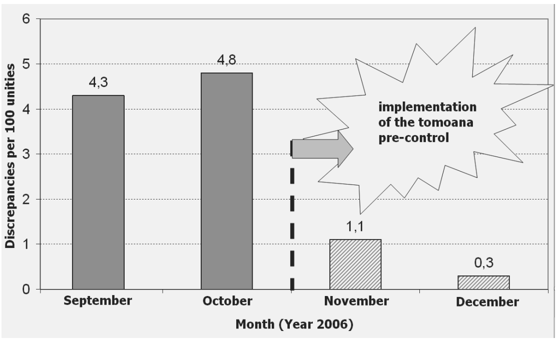

Fig. 11. External customer discrepancies Chart (Export)

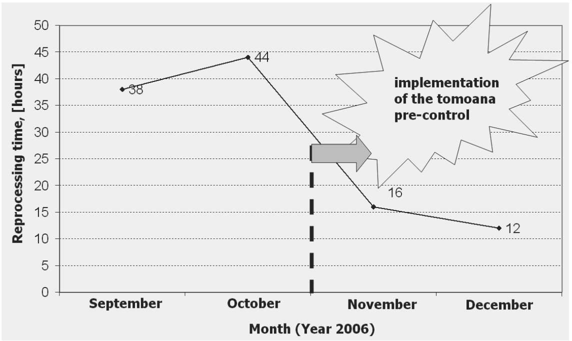

Fig. 12. Subassembly rework hour Chart per month

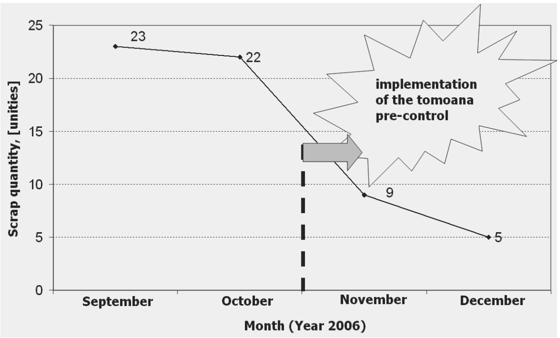

Fig. 13. Subassemblies Scrap Chart

8. Conclusions

The application of the pre-control methodology revealed viable in the manufacture process, in particular in the process of automotive body-in-white subassemblies, to complement the current methods of dimensional control.

The pre-control, revealed as a simplified tool application and can be used by the production operators with low investment cost and operation.

There was an improvement in body-in-white dimensional stability which the subassemblies had been submitted to the pre-control process, “tomoana”, what it proves the effectiveness and benefits of the method.

The method guarantees greater detention and reduces the losses in function the process variations in the body-in-white assembly process.

The application is more efficient in subassemblies manufactured from manual process or that allows greater interaction of the production operator.

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