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ELIMINATION OF FINAL DIMENSIONAL INSPECTION WITH R&R APPLICATION - A CASE STUDY

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PRESENTATION

Paper presented at the University of Taubaté, São Paulo Brazil, in partial fulfillment of the requirements for the master's degree in mechanical engineering with emphasis on Mechanical Production.

ELIMINATION OF FINAL DIMENSIONAL INSPECTION WITH R&R APPLICATION - A CASE STUDY

Abstract. *This work aims to present the application of the study of repeatability and reproducibility (R & R) in the search for the elimination of final dimensional inspection in a company in the railway sector, in order to seek cost reduction without reduction of product quality. This way, an R & R study was carried out, with operators and inspectors, in order to reach the objective of this work. Finally, considering this approach, this work uses the case study method to demonstrate, with the results presented by the R&R study, the possibility of eliminating the final dimensional inspection.*

Keywords: *R&R Study, Elimination of Final Dimensional Inspection, Railway Sector.*

1. INTRODUCTION

With globalization, an intense wave is facing an unprecedented competition in the market new competitiveness benchmarks are established (Galdamez; Carpinetti; Gerolamo, 2009; Chiavenato, 2016). The railroad sector, just as any other sector, has been seeking to increase its competitive value, where cost reduction is especially sought (Villas Bôas, 2010).

The success of a company depends not only on its products, services, but on a series of decisions, actions, skills, strategies, etc. (Chiavenato, 2016). Therefore, investing in quality becomes essential for the company to maintain its competitiveness; to be competitive, the company must offer quality products with the lowest costs of production, reducing unnecessary costs and expenses (Feigenbaum, 1994; Peixoto; Bastos, 2012).

With this in mind, the company's focus on quality should be the search for tools that help the production process, in order to improve it continuously, increasing the company's competitiveness (Oliveira; Martins, 2008). The problem is that, even today, micro, small and medium-sized companies, usually have poor quality management and a low level of organizational maturity (Takahashi, 2016). This can be linked to intuitive decision-making, since managers are often based on informal sources, not paying attention to production statistics and technical-scientific materials (Araujo *et. al.*, 2015).

The study of Repetitivity and Reproducibility (R&R) within the production process is in line with the continuous search (Shi; Chen; Fu Lu, 2014), and used in the article as an evaluation tool to determine the possibility of the elimination of thee final dimensional inspection, in order to reduce costs of production; even with the development of lean manufacturing system, the inspection process should be eliminated because it is considered a waste (Carvalho; Paladini, 2006).

This work aims to present an analysis of the results of measurements among inspectors and operators to eliminate the final dimensional inspection in a medium-sized company in the railway sector, based on the R&R study method to reduce the costs without changing the quality of the product.

2. THEORETICAL BACKGROUND

2.1. Repeatability and Reproducibility Studies (R&R)

R&R (Repeatability and Reproducibility) studies are used for the improvement of quality control, being applied to determine the capabilities of the measurement system (Shi; Chen; Fu Lu; 2014). Repeatability and reproducibility are defined as:

"*Repeatability – measurement condition within a set of conditions, which includes the same measurement procedure, the same operators, the same measurement system, the same operational conditions, and the same place, as well as repeated measurements of the same object or similar objects over a short period of time*" (Inmetro, 2012).

"*Reproducibility – measurement condition in a set of conditions, which includes different places, different operators, different measurement systems, and repeated measurements of the same object or similar objects*" (Inmetro, 2012).

Thus, repeatability is the variation of the measured values within the system, with the same set of standards and operators, and reproducibility is the variation obtained by different operators and set of standards within the system (Azevedo *et. al.*, 2013). Figure 01 represents the terms of repeatability and reproducibility.

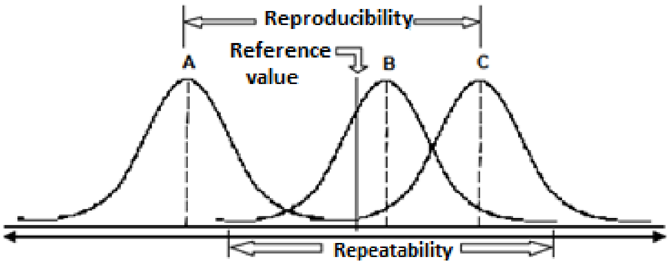


Figure 01. Concept of repeatability and reproducibility (Silva, 2005).

2.2. R&R Calculations

The MSA (Measurement Systems Analysis) manual, by Automotive Industries Action Group

- AIAG (2010), presents a set of procedures whose objective is to evaluate the measurement systems belonging to a given quality system (Abackerli *et. al.*, 2015). According to AIAG (2010), There are several methods to calculate R&R; however, the most accepted ones are: the interval method, the average amplitude method, and the ANOVA method.

In an R&R study, the criteria to define whether a measurement system is satisfactory or not is given by the MSA manual (Soares Júnior; Albertin; Silva, 2011):

● R&R value ≤ 10%, measurement system is considered acceptable;

● R&R value > 10% and ≤ 30%, measurement system can be accepted — based on the importance of its application, on the cost of the measurement equipment, among other factors. However, the system must be improved;

● R&R value > 30%, measurement system is considered unacceptable.

2.3. The Interval Method

The interval method is a quick study providing a superficial overview, since it does not decompose the entire system of variability of repeatability and reproducibility; it is typically used to verify that Gage R&R (Gage Repeatability and Reproducibility) has not been changed (AIAG, 2010).

2.4. The Average Amplitude Method

It is used to provide more complete information about the measurement system, based on the sample mean ($\bar{\bar{x}}$) and the sample amplitude ($\bar{R}$). It allows decomposition of the components, so it is possible to identify and take corrective actions, if necessary. Exemplified, if the repeatability component (σrepe) compared to the reproducibility component (σrepro) is higher, the instrument may be damaged, requiring maintenance or the measurement site needs to be overhauled; if the contrary is verified, the operator may be using the measuring instrument improperly, the reading of the instrument may not be clear, the measurement procedure may / should be reviewed (Abackerli *et. al.,* 2015).

2.5. The Anova Method

It is the most accurate for the study of R&R and also more complex (Arbeláez; Salazar; Vargas, 2007). The ANOVA method requires software to perform the calculations and statistical tables, which makes it more time-consuming (Silva, 2005). The ANOVA method decomposes into four categories: parts, evaluators, interaction between parts and evaluators, and replication error due to the measurement instrument (AIAG, 2010). A guide for the R&R study can be carried out following the formulas of Table A3 of the MSA Manual 4ª edition, or ANOVA Table (Arbeláez;

Salazar; Vargas, 2007; AIAG, 2010).

2.6. Rail Wheel

Rail wheels can be forged or cast. The main difference is in the manufacturing process and wheels application (Minicucci, 2003). Cast wheels can only be used in cargo transportation (freight cars), while forged wheels can be used in any type of transportation: cargo, passengers, and locomotives (Minicucci, 2011).

For a better understanding, Figure 02 shows the drawing (in section) of a railway wheel, also illustrating a nomenclature of each region of the wheel.

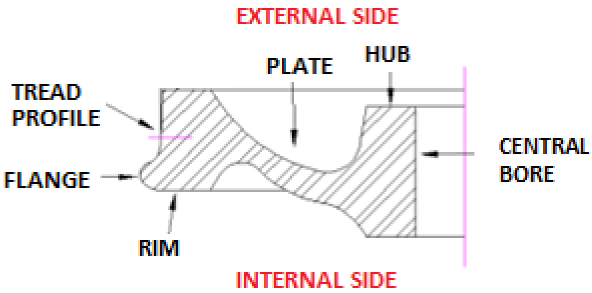


Figure 02. Rail wheel nomenclature (Adapted from Villas Bôas, 2010).

The railroad market in Brazil mostly follows the specifications of the North American regulation of the rail industry, Association of American Railroads (AAR). Railway wheels, for the most part, are produced by steel with a percentage of Carbon (C) between 0.67 and 0.77, classified as "Class C" (AAR, 2016). However, there are other classes, exemplified by Table 01.

Table 1. Chemical composition and hardness (AAR, 2016).

CHEMICAL COMPOSITION	CLASS				
	L	A	B	C	D
Carbon (C)	<0,47	0,47 - 0,57	0,57 - 0,67	0,67 - 0,77	0,67 - 0,77
Manganese (Mn)	0,60 - 0,90	0,60 - 0,90	0,60 - 0,90	0,60 - 0,90	0,60 - 0,90
Phosphorus (P)	<0,03	<0,03	<0,03	<0,03	<0,03
Sulfur (S)	0,005 - 0,04	0,005 - 0,04	0,005 - 0,04	0,005 - 0,04	0,005 - 0,04
Silicon (Si)	0,15 - 1	0,15 - 1	0,15 - 1	0,15 - 1	0,15 - 1
Hardness (BHN)	197 - 277	255 - 321	302 - 363	321 - 363	341 - 415

3. METHODOLOGY

The nature of this work is applied research, according to Mello & Turrioni (2012), seeking to expose a certain problem in order to correct it with practical application; being added the commercial scenario, one of the characteristics of the applied research, since it also has a role of optimization of the manufacturing process, since the objective is the exclusion of the final dimensional inspection, directing in this way for the costs reduction, according to the need of market.

With regard to the objectives, the article is classified as exploratory, because it has as a characteristic to explore and make the problem comprehensible, through the accomplishment of: bibliographical survey and experiment, thus enabling a greater clarity to the reader.

As for the approach, the quantitative approach was used with the application of the R&R method, generating numerical results for analysis. Eleven (11) operators and three (3) inspectors were randomly selected for railroad wheel measurement under the same conditions.

Finally, the method adopted was a case study, because it presents a problem that does not have a predefined solution, requiring commitment of the management of the company, aiming to identify the problem, analyse evidence, develop logical arguments, evaluate and propose solutions, being this one of the most suitable for this case, according to Silva & Menezes (2005).

4. RESULTS AND DISCUSSION

The current machining process of the company studied is basically composed of 5 machining operations. In each operation, one or more dimensional and geometric characteristics are generated, and must be controlled by the operator. That is, a 100% inspection is carried out on the railway wheels during the machining process.

After machining, the wheels are taken to the inspection line, where an ultrasound examination is performed, as well as magnetic particle, hardness, and final dimension checks, as seen on the following inspection line flowchart.

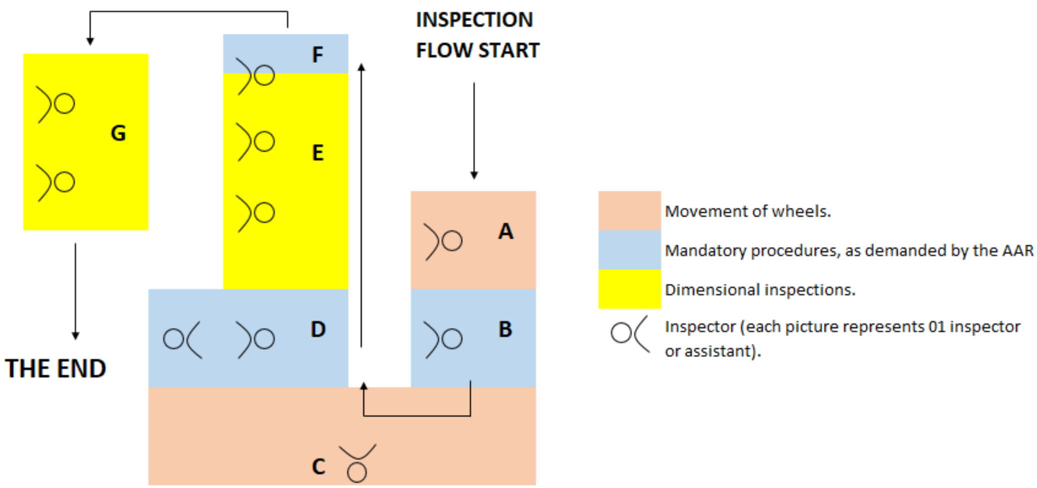


Figure 03. Inspection line flowchart (Authors, 2017).

Steps A and C are movement/supply steps. Since the wheels are not automatically moved within the inspection line, an inspection assistant is designated for each one of those procedures.

Steps B, D, and F are mandatory procedures for all rail wheels produced, as demanded by the AAR standards. The steps are as follows:

- Ultrasound - where 1 (one) inspector follows the inspection being made by the automated machine, being responsible for any required adjustments for the inspection standards of rail wheels and for the final inspection itself.
- Magnetic particle - 2 (two) inspectors are responsible for this stage, each one inspecting one side of the wheels (internally and externally). Contrary to ultrasound inspection, magnetic particle check is made manually, where the inspectors are responsible for the detection or of surface and/or internal cracks.
- Hardness measurement - 1 (one) inspector is responsible for rail wheels the hardness measuring and registration.

Steps E and F refer to dimensional inspections, with 4 to 5 inspectors participating in those activities.

As seen in Figure 03, there are 2 assistants and 8 inspectors participating in the process, with 1 inspector working on the dimensional (E) as well as on the hardness (F) measurements. Therefore, there are 10 people involved in the inspection line process.

Based on the assumption that all rail wheels have their own processes and drawings showing in detail to the operator the tolerance limits to be controlled in each operation, and knowing that the same inspector performs the measurements in the respective steps of the machining process, there would be no reasonable reasons for the repetition of the dimensional measurement. It means that here is an opportunity of gain in terms of reduction cost and time wasted within the rail wheel production process.

Thus, with the purpose of verifying the measurement capabilities of the operators, so that it could be possible to eliminate the final dimensional inspection, an experiment was conducted where 11 (eleven) operators and 3 (three) inspectors performed the measurement of 2 (two) rail wheels, within the same environment and with the same instruments. To that end, the wheels were divided into 4 (four) areas to be measured by the operators and the inspectors. Figure 04 illustrates the division.

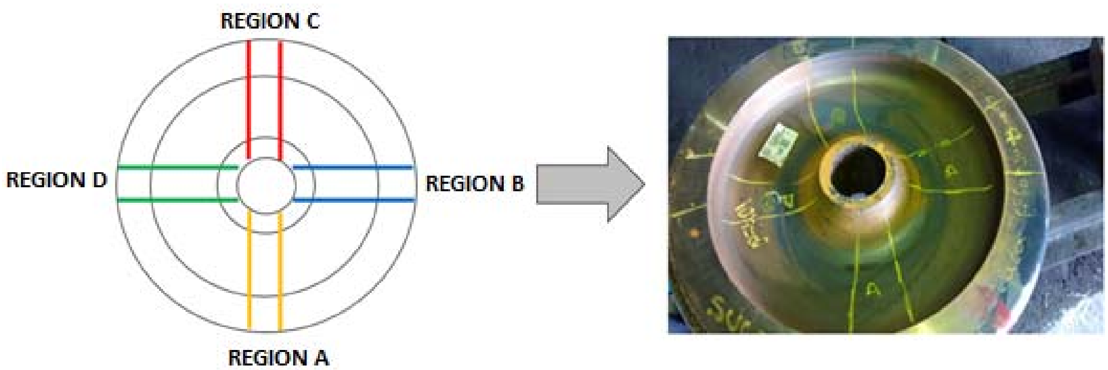


Figure 04. Detail of the divided areas of the wheel (Authors, 2017).

The operators and inspectors performed the measurement of 5 characteristics / dimensions: Dimension L, Thickness of the rim; Dimension P, Cube length (contact region in the assembly with the rail axles); Dimension R2, Distance from the face of the cube in relation to the face of the rim; Dimension G1, Wheel rim width, also known as "life" (this is one of the regions used to track wheel wear); and dimension D, the wheel diameter.

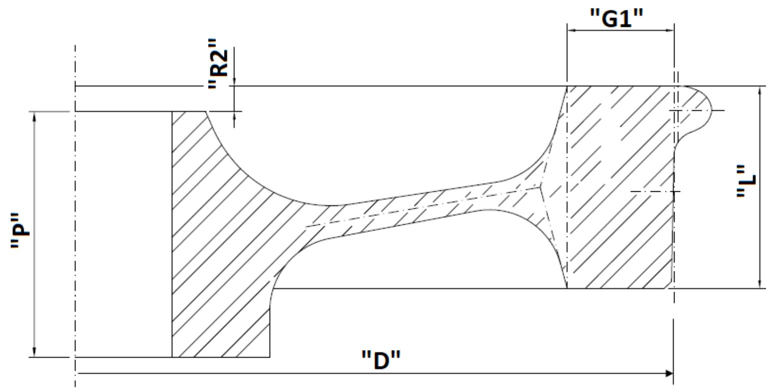


Figure 05. Characteristics detail (Authors, 2017).

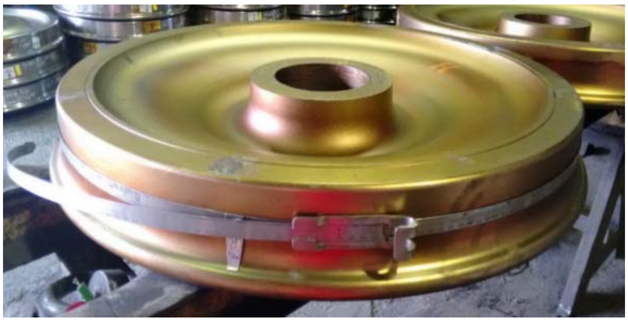


Figure 06. Ilustration of method of measure, dimension D (Authors, 2017).

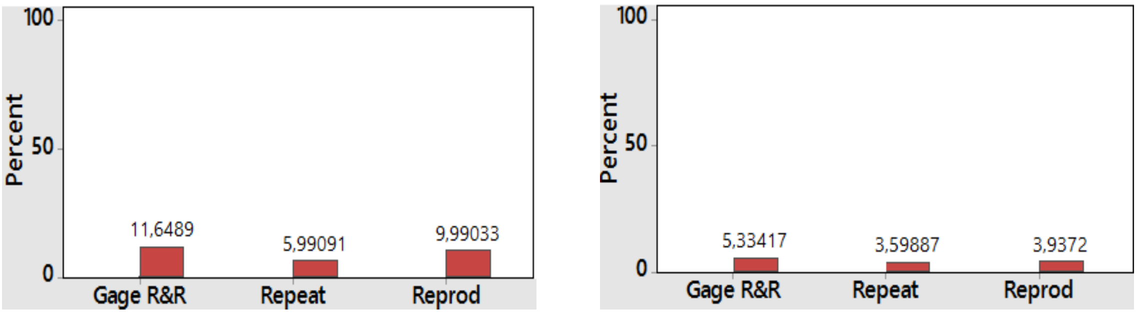
Table 2. Results of measurements performed by operators and inspectors (Authors, 2017).

WHEEL 01																				
RESPONSIBLE FOR MEASUREMENT	DIMENSION L				DIMENSION P				DIMENSION D				DIMENSION R2				DIMENSION G1			
	REGION				REGION				REGION				REGION				REGION			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Operator 01	141,7	141,6	141,6	141,7	176,9	176,7	176,8	176,9	234	234	234	234	17,73	17,74	17,74	17,74	76,0	76,0	76,0	75,0
Operator 02	141,7	141,5	141,5	141,7	176,8	176,8	176,8	177,0	234	234	234	234	17,72	17,74	17,74	17,74	75,0	76,0	75,5	75,0
Operator 03	141,4	141,4	141,5	141,5	176,6	176,6	176,8	176,6	234	234	234	234	17,73	17,73	17,73	17,73	76,0	76,0	76,0	76,0
Operator 04	141,4	141,4	141,4	141,4	176,0	176,5	176,5	176,5	234	234	234	234	17,74	17,74	17,74	17,74	76,0	76,0	75,0	75,0
Operator 05	141,4	141,4	141,4	141,6	176,8	176,6	176,6	176,8	234	234	234	234	17,74	17,74	17,74	17,74	76,0	76,0	75,5	75,0
Operator 06	141,4	141,5	141,5	141,4	176,7	176,8	176,7	176,7	234	234	234	234	17,74	17,73	17,74	17,74	76,0	76,0	76,0	76,0
Operator 07	141,5	141,5	141,5	141,6	176,7	176,6	176,6	176,7	234	234	234	234	17,74	17,74	17,74	17,74	76,0	76,0	76,0	76,0
Operator 08	141,8	141,7	142,0	141,7	176,5	176,5	176,8	176,8	234	234	234	234	17,72	17,72	17,72	17,72	76,0	76,5	76,0	76,0
Operator 09	141,2	141,2	141,2	141,4	176,5	176,6	176,5	176,5	234	234	234	234	17,74	17,74	17,74	17,74	76,0	76,0	76,0	76,0
Operator 10	141,4	141,5	141,4	141,4	176,6	176,6	176,6	176,6	234	234	234	234	17,74	17,74	17,74	17,74	75,0	76,0	76,0	75,0
Operator 11	141,4	141,5	141,5	141,5	176,7	176,6	176,7	176,7	234	234	234	234	17,73	17,73	17,73	17,73	76,0	76,0	76,0	76,0
Inspector 01	141,4	141,4	141,3	141,4	176,9	176,8	177,0	177,1	234	234	234	234	17,74	17,74	17,74	17,74	76,0	76,0	76,0	76,0
Inspector 02	141,5	141,4	141,6	141,5	176,8	176,7	176,8	176,6	234	234	234	234	17,74	17,74	17,74	17,74	76,0	75,0	75,0	75,0
Inspector 03	141,2	141,3	141,2	141,3	176,6	177,0	176,6	176,8	234	234	234	234	17,73	17,73	17,73	17,73	76,0	76,0	75,0	75,0

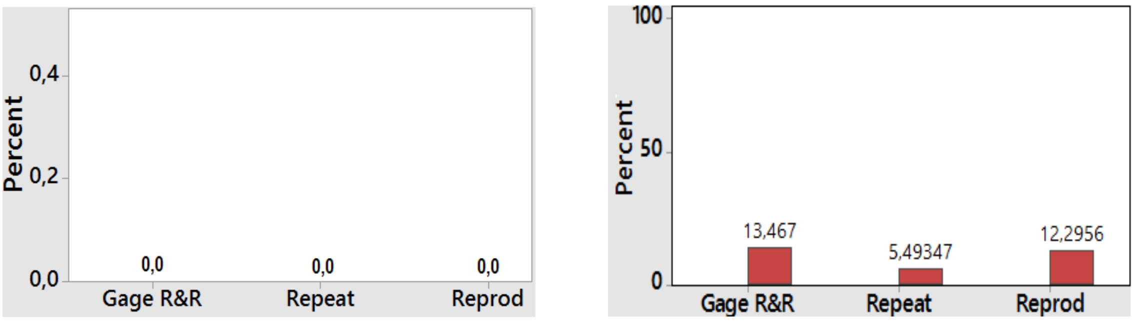
WHEEL 02																				
RESPONSÁVEL PELA MEDIÇÃO	DIMENSION L				DIMENSION P				DIMENSION D				DIMENSION R2				DIMENSION G1			
	REGION				REGION				REGION				REGION				REGION			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Operator 01	140,0	140,1	140,1	140,2	173,0	173,2	173,1	173,1	234	234	234	234	17,80	17,80	17,80	17,80	75,0	75,0	75,0	75,0
Operator 02	140,0	140,1	140,0	140,0	173,0	173,1	173,0	173,0	234	234	234	234	17,81	17,81	17,81	17,81	75,0	75,0	75,0	76,0
Operator 03	140,0	140,0	140,0	139,9	172,9	172,9	172,9	172,9	234	234	234	234	17,81	17,81	17,81	17,81	75,0	75,0	75,0	75,0
Operator 04	140,0	140,0	140,0	140,0	173,0	173,0	173,0	173,0	234	234	234	234	17,80	17,80	17,81	17,80	75,0	75,0	75,0	75,0
Operator 05	140,0	140,0	140,0	140,0	172,9	173,0	172,8	173,0	234	234	234	234	17,80	17,80	17,80	17,80	75,0	75,0	75,0	75,0
Operator 06	140,0	140,0	139,9	140,1	173,0	172,8	172,9	172,8	234	234	234	234	17,80	17,80	17,80	17,80	76,0	75,0	75,5	75,5
Operator 07	140,0	140,0	139,95	140,0	173,0	173,0	172,9	172,9	234	234	234	234	17,81	17,80	17,80	17,80	75,5	76,0	76,0	76,0
Operator 08	140,0	140,1	140,00	140,0	173,0	173,0	173,0	173,0	234	234	234	234	17,82	17,82	17,82	17,82	75,0	75,0	75,5	75,5
Operator 09	139,9	139,9	139,80	139,9	172,8	172,9	172,8	172,9	234	234	234	234	17,80	17,80	17,80	17,80	76,0	76,0	76,0	76,0
Operator 10	140,0	140,0	140,0	140,0	172,8	172,8	172,8	172,8	234	234	234	234	17,80	17,80	17,80	17,81	75,0	75,0	75,0	75,0
Operator 11	140,0	140,0	139,95	140,0	173,0	173,0	173,0	173,0	234	234	234	234	17,80	17,80	17,80	17,80	75,5	75,5	76,0	75,5
Inspector 01	140,0	140,0	140,0	140,0	173,0	173,0	173,0	173,0	234	234	234	234	17,81	17,81	17,81	17,81	75,0	75,0	75,0	75,0
Inspector 02	140,1	140,1	140,0	140,1	173,0	172,9	173,0	173,0	234	234	234	234	17,80	17,80	17,80	17,80	75,0	75,0	75,0	75,0
Inspector 03	140,0	140,0	140,0	140,0	172,9	173,0	172,8	173,0	234	234	234	234	17,80	17,80	17,80	17,80	75,0	75,0	75,0	75,0

With the data collected (Table 02) it was possible to conduct an R&R study, based on the ANOVA method and using the Minitab 17® statistical software. The results of the analysis are shown in graphs 1, 2, 3 and 4, where it is possible to verify the repeatability (σrepe) and reproducibility (σrepro) components, as well as the percentage of the Gauge Repeatability and Reproducibility (GRR).

Graph 1 and 2. R&R study, dimension L, left, and dimension P, right (Authors, 2017).



Graph 3 and 4. R&R study, dimension D, left, and dimension R2, rigth (Authors, 2017).



5. FINAL CONSIDERATIONS

As stated in this work, the company under study, has a great potential to implement a system to eliminate the final dimensional inspection, in face of the acceptable results gathered by the R&R analysis, according to the MSA manual. If implemented, costs could be reduced considerably with the elimination of labor costs in the inspection line and the reduction of the time used in the process.

However, it is necessary to analyse the measuring instruments defined for use during the machining process, in order to validate them, as carried out in this article, and the application of training for the qualification and / or improvement of the operators in the measurements, since in the year 2016, 8.13% of the railway wheels were identified by the final dimensional inspection sector as non -conforming, being: 7.30% returned to the rework machining sector and 0.83% scrap, without the possibility of reworking.

As a last provision, it is also fundamental to begin a change of mentality of everyone involved in the process. As the final part of it — for machining operators are what is between the wheel and the client in terms of dimensional aspects —, it is very important to acknowledge the critical role they play in the quality process. Thus, developing in them a sense of quality awareness, will prevent the avoidance of reporting dimensional nonconformities, even minor ones.

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