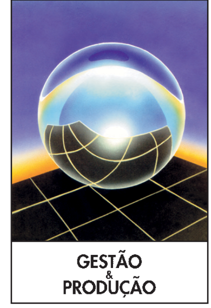
Gest. Prod., São Carlos, v. 25, n. 2, p. 343-353, 2018
http://dx.doi.org/10.1590/0104-530X3094-16



ISSN 0104-530X (Print)
ISSN 1806-9649 (Online)

Comparison between Cold and Hot Test procedures in a company manufacturer of diesel engines

Comparação entre os processos de Cold Test e Hot Test em uma empresa fabricante de motores diesel

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Abstract: The Cold Test is an innovative process in Brazil regarding the tests in diesel engines. This process was implemented in a diesel engine company with the intention of becoming the main validation test before engines are sent to customers. Based on this hypothesis, the main reason of this investigation is to test whether it is possible to replace the Hot Test with the Cold Test. This was a shocking question, since the Hot Test is a reliable and established process for over 18 years. This research used a case study method. The detailed research has identified several criteria for comparing the two processes, such as: flowcharts, effectiveness, efficiency, complexity, approval levels, on-board worksheets and company FMEA documents. The results showed that the Cold Test process is more advantageous and sustainable, however the two processes are complementary. The study proved that the fully replacement of the Hot Test by the Cold Test is not possible, mainly the Cold Test process fails in detecting leaks.

Keywords: Cold Test; Hot Test; Diesel engines; Processes; PDCA.

Resumo: *O teste a frio (Cold Test) é um processo inovador no Brasil com relação aos testes em motores diesel. Esse processo foi implementado em uma empresa fabricante de motores diesel, com o intuito de ser o principal teste de validação antes de os motores serem enviados ao cliente. Partindo-se dessa hipótese, surgiu o principal motivo desta investigação: é possível a substituição plena do teste a quente (Hot Test) pelo teste a frio (Cold Test)? Essa foi uma pergunta impactante, visto que o Hot Test é um processo confiável e consagrado há mais de 18 anos. O método utilizado nesta pesquisa foi o estudo de caso. A investigação detalhada identificou vários critérios de comparação dos dois processos, tais como: fluxogramas, eficácia, eficiência, complexidade, níveis de aprovação, planilhas de bordo e documentos FMEA da empresa. Os resultados mostraram que o processo Cold Test é mais vantajoso e sustentável, entretanto os dois processos são complementares. O estudo comprovou que não foi possível a plena substituição do Hot Test pelo Cold Test, principalmente pelo fato da não detecção de vazamentos no processo Cold Test.*

Palavras-chave: *Cold Test; Hot Test; Motores diesel; Processos; PDCA.*

1 Introduction

This study was carried out in factory environment, specifically at the end of a diesel engines assembly line. Most manufacturers test their engines after fully prepared in rooms or bench tests. This test process is called *Hot Test*, the engines are tested under the conditions of the vehicle. (Atkins, 2009; Ferguson & Kirkpatrick, 2015; Martyr & Plint, 2011). However, it has been gaining space in the quality assessment y of engines another method called *Cold Test*, which does not need engine combustion (Delvecchio, 2012; Delvecchio et al., 2007; Gagneur, 1999).

The two processes run different activities, but with the same purpose, certify that the engines are one hundred per cent reliable to be sent to the assembler. The main difference between these two methods, is that in the Hot Test, the engine performs the combustion, while the Cold Test there is not need of combustion. For this the *Cold Test* counts on different forms of waves emission, in order to represent the pressures and engine vibration and, thus, perform the necessary assessments (Gagneur, 1999; Martyr & Plint, 2011, 2012).

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Received Apr. 18, 2016 - Accepted Dec. 6, 2016

Financial support: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES/PROSUP).

The evolution of the use of *Cold Test* in petrol engines and the same trend in diesel engines, whether by market requirements or by reducing test time and even reducing environmental impact, show a tendency for its use (Delvecchio, 2012; Delvecchio et al., 2007). Thus, this research finds its motivation from the following question: In the case of diesel engines, is it possible the full replacement of *Hot Test* by the *Cold Test*?

In order to answer the question raised, this article wants to map, analyze and compare *Cold Test* and *Hot Test* processes, with the main objective of assessing whether a process can replace the other, or if they are complementary. Since that these two tests have the same purpose, check the final quality of the engines prior to validate and send to customers. This scientific experiment seeks to serve as a document of lessons learned from the two pieces of equipment for future consultations, identify technical differences of Cold Test and Hot Test processes.

This operation also aims to identify the benefits of deploying Cold Test, as well as the approval requirements of the Hot Test and Cold Test and their limiting factors. It also aims to, verify what process may be considered more sustainable, in the sense of minimal environmental impact and use of natural resources.

In the academic field, it is intended to contribute to studies on the Cold Test process, since in Brazil, according to research, the literature on this subject is summarized. The present study also hopes to cooperate for the studies of Mechanical Production Engineering, with the matters related to the Hot Test Cold Test and the comparison of the two processes.

Finally, the study presents the most relevant comparative results and answers the main question, whether or not it is possible the full replacement a consecrated quality test for more than 18 years, by new technology called Cold Test. This quality test is a guarantee final process in 100% of the engines. It is also important to note also that the work demonstrates the company's concern with the environment, given that, upon implementing the technology Cold Test the company aims for sustainability.

2 Theoretical framework

The literature review was performed in the national databases (Capes, Tede) and international (Ebsco Host, Scielo, Dart Europe and Google Scholar). The key words found in national databases had the following titles: *teste em motores diesel, motores diesel, teste a frio, Cold Test, Cold Test X Hot Test nas indústrias automotivas and Cold Test nas indústrias automotivas.* The indexes defined were in exact areas and engineering. With respect to the temporal amplitude, there was limited time. In the research of international scope in addition to the titles in English described the following titles in English were used: *Cold Test engine, Engine testing, Cold Test X Hot Test in the automotive, Cold Testing, Cold Test in the automotive*.

The searches in each database with their proper filters resulted in 1,977 (one thousand nine hundred and seventy-seven) entries. The analysis of the information consisted in reading the title of each entry. After reading the titles, 127 (one hundred and twenty-seven) *resumos* (abstracts) were read which could have relevance for this research, in accordance with the proposed objective. Due to the reading of abstracts 17 (seventeen) relevant work or that have contributed in some way to this research were separated. At the end of the analysis of the collected information, it was not evidenced Brazilian publications regarding the Cold Test process.

The theoretical framework of this study, discusses some of the methods of preparation and control, employed in the processes for quality assurance in the manufacture of diesel engines. It explains in general lines, what the processes Hot Test and Cold Test are. It presents their structures, operation and makes a brief comparison between the two processes. It also shows that the full or partial replacement of the hot Test by Cold Test can be considered a technological improvement for the improvement of the manufacturing process, reducing emissions and losses. All of them are considered important items for the automotive sector.

2.1 The Hot test process

In *Hot Test process*, also called bench tests, the engines are started and tested as if they were in their respective vehicles. The operation of this process consists basically of a dynamometer brake that absorbs the energy produced in the engine, in a scheme of operation controlled by an automated system, with control parameters of speed and rotation (Ferguson & Kirkpatrick 2015; Martins, 2013; Pereira, 2009; Serrano, 2012).

Some typical projects of Hot Test are performed under load, with review benches, with the aim of reconstruction and tests of motors engineering. Such stalls need an appropriate area with the following supplies: (A) water supply and sewage; (b) system of fuel supplies; (c) adequate ventilation; (d) the engine exhaust system for the outside; (e) acoustic insulation; (f) security system and precautions against fire (Atkins, 2009; Martyr & Plint 2011; Serrano, 2012).

According to Atkins (2009), there are many types of engines tests in the industry, the main ones are: (1) Durability test; (2) Performance test; (3) lubricant and fuel test; (4) special investigations; (5) test of exhaustion system; (6) catalysis agent test. This study covers only the performance test, developed by the engine manufacturer. According to Pereira (2009), usually there is a template report to record the values measured during the production test at the end of the assembly line.

According to Pereira (2009), Performance test is widely used in diesel automotive engines, being performed at full load. In this test the throttle is in the position of maximum speed with applications of loads of 25%, 50% and 75%. This will determine the maximum engine power in each rotation of its operation, according to pre-requisites of quality.

Martyr & Plint (2012) describe the procedure necessary for the process of Hot Test, as being the activities of handling the engine, adjustments, mounting, filling, starting the engine, drain and the sequence of real test; all this is highly automated. Any interventions identifications of failures are performed by an experienced tester. The detection of leakage can be difficult in a Hot Test, therefore, it is often performed in a special station (Black-light).

2.2 The Cold Test process

The Cold Test, in turn, consists of analyzes of engine waves forms under test, compared with patterns of a perfect engine, without combustion. The key element of the Cold Test is the development and maintenance of large amounts of data that form a computerized system for analyzes and comparisons (Fogaça et al. 2014; Mudge & Rice, 1984; Scourtes et al., 1994).

The big advantage in cold test is the elimination of ignition and, consequently, engine combustion in the hour of test, because the motor is rotated by an electric motor attached to its axis. The rotation speed of the engine in which the tests are performed is low and the supply of signals has extreme precision. Thus, the reduction of speeds and loads of test will minimize the damage of a faulty engine (Gagneur, 1999; Martyr & Plint, 2012; Thyssen Krupp, 2011).

A *Cold Test* station does not require much of assay laboratory infrastructure when compared to a *Hot Test Standard*. There is no need for exhaust systems and dedicated ventilation, fire risks are smaller, the fuel system and the attenuation of the noise are simplified. The engine test is connected by an electric motor, thus, there is no combustion in the test (Martyr & Plint, 2012).

According to the authors Martyr & Plint (2012) the Cold test generally includes:

a) pressure curve of oil over time to check the oil pump and the integrity of the engine oil circuit;

b) Starting torque of the engine during the test sequence, which indicate the pistons or bearings too tight or poor governed;

c) Synchronism between the crankshaft and command;

d) Verification of pressure pulsations of Common Rail. System in which fuel injection occurs several times during the supply cycle (Serrano, 2012);

e) Checking the air flow of intake and exhaust, operation of the valve of compression;

f) Test of electric wiring integrity, performed at the same station of the test.

The forms of standard waves/signature for any signal are similar for normal or faulty engines. In case of a faulty engine, the data observed are abnormal, consequently, the wave forms are changed. With this knowledge, it is possible to detect the defects automatically on engines and also point out the root cause of the problem. The problem is corrected before damaging the engine (Thyssen Krupp, 2011).

2.3 Cold Test versus Hot Test

According to Gagneur (1999), for many years, manufacturers of diesel engines depended exclusively on the Hot Test, at the end of their production lines, to identify defects and guarantee the quality. But, in most cases, the hot test may only be able to identify the effects of the problem, as for example, the low oil pressure, not providing information about the cause of the problem, such as a defective oil pump. On the other hand, the Cold Test monitors the electrical signals from the oil pump and its curve of pressure since the beginning of its operation until it is turned off. Identifying, thus the cause of the engine low pressure.

The test bench is designed to read the identity codes in the engine, recognize variants, and to adjust the approval or disapproval in accordance with the criteria of the quality of the company. During the manufacturing test two measurements are vital to the integrity of the construction of the engine, checking the torque and the time required for the oil pressure reaches its normal level. This process executed at the “manufacturing shop floors” has a duration of 5 and 8 minutes (Delvecchio et al., 2007).

These elevated times of tests are becoming increasingly rare and subjected to short periods of testing on dynamometers. However, the Cold Test, performs the same test in a shorter time, so it has been a more common practice, especially in small-sized engines. In these engines, it is common the passage of 100% of production in Cold Test process and only a small percentage on the Hot Test (Gagneur, 1999).

The technology Cold Test reinforces the constant concern with respect to safety, since the operator does not approach the engine while it is in movement, so the risks to people are minimized. In addition, its noise is around 50 dB (decibels), consequently the machine does not need to be enclosed as the bench tests. Another important benefit of the Cold Test is the detection of failures before the parts are loose or even break, due to dynamic analysis of its vibration sensors (Delvecchio, 2012; Martyr & Plint, 2012).

However, according to Gagneur (1999), there are some limitations inherent to the Cold Test process, as for example the leaks. The leaks are caused by differential expansion of the components during engine warm-up. They are not clear and the flows of its fluids are lower, compared to the Hot Test. Therefore, such manufacturing flaws or components are not identified in the Cold Test.

3 Methodology

The survey strategy is the case study, the main method of this study, since the empirical research took placing a specific automotive company, located in the southern region of Brazil. This research aims to be descriptive as the processes of Hot Test and Cold Test will be described. But it will also be explanatory since the objective is to analyze the similarities and differences between the two processes (Yin, 2015).

This case study aims to demonstrate that it is possible to replace two processes of quality assurance, Hot Test by the Cold Test. Then it was carried out a theoretical study of the two processes, identifying their key requirements; The field research has identified the key requirements for the approval of the engines tested. Flaws' of processes, troubleshooting, calibration of equipment and requirements of quality (Lacerda et al., 2013).

The main data collection comes from the analysis of the tests, indexes and reports of the two processes: Hot Test and Cold Test during the period of 2011, year of the implementation of the Cold Test in the Company, until March 2014. The interviews are the unstructured type, being held several times during the research, in both cases, with testers in the first and second shifts, process and maintenance technicians, process, maintenance and quality engineers. Overall 18 people involved in both processes were interviewed.

According to Antunes et al. (2013), in order to detail the jobs position (GPT) at the entrances of the systems, it is sought information in the equipment manuals, company documents, analysis of failures (FMEA) and interviews. The FMEA document is based on the Automotive Industry Action Group (AIAG, 2008). The primary technique of analysis is the comparison between the two processes through the identification of the pattern of occurrences and the investigation in detail of the main causes for the same.

The working method adopted was Harrington (1993), where the author proposes the management of the process through the following steps: (A) mapping; (b); analysis (c) implementation and (d) maintenance. The main objective is to show the relevant characteristics, the approval requirements and the limits of each process, putting them in a same basis, thereby facilitating the comparison between the two.

4 Comparison of the processes Hot test and Cold Test

For the comparison of the two processes information was collected from the Hot Test and the Cold Test. The comparison of the two processes is based and built by various criteria such as: flow charts, effectiveness, efficiency, complexity, levels of approval with respect to the tests performed, logbook spreadsheets and FMEA documents of the company.

The issue of full replacement is a very relevant question, because the initial idea with the purchase of the Cold Test was to make it the only process, in which 100% of engines would be tested. However, the company still uses (2016) the two processes working simultaneously, and all engines tested first in the Cold Test and then the Hot Test.

4.1 Processes mapping

For the processes mapping the following criteria were performed and analyzed: (A) process flow; (b) cycle time; (c) Effectiveness; and (d) efficiency (Harrington, 1993).

Processes flow: To facilitate the organization of thought in the comparison of the two processes two flowcharts were created. These charts show the activities and tasks developed in the two proceedings allowing: to check the common points; activities that do not add value; the points of checks; points of decisions and measurements of quality.

Viewing the two flowcharts in Figure 1, it is noted that the Hot Test process has more activities that the Cold Test process. The addition of activities on the Hot Test begins with the availability of Bench Tests, when the three benches are occupied, the engines are directed to the waiting points. As soon as the Benches end their tests, the engines leave their waiting points and are directed to the respective free bench.

The opening and closing of the doors where the pallets enter, with the engines to be tested and the entrance and exit of the tester of each bench, increase the time of the process. The interconnection of the engines with the Bench tests with their equipment is performed automatically. The pallets are built to connect to the tests quickly and with the least possible operational work force. The time for heating and deceleration of the engine on the test, necessary in order not to damage the engine, increases the activities needed in automatic cycle. The leak tests

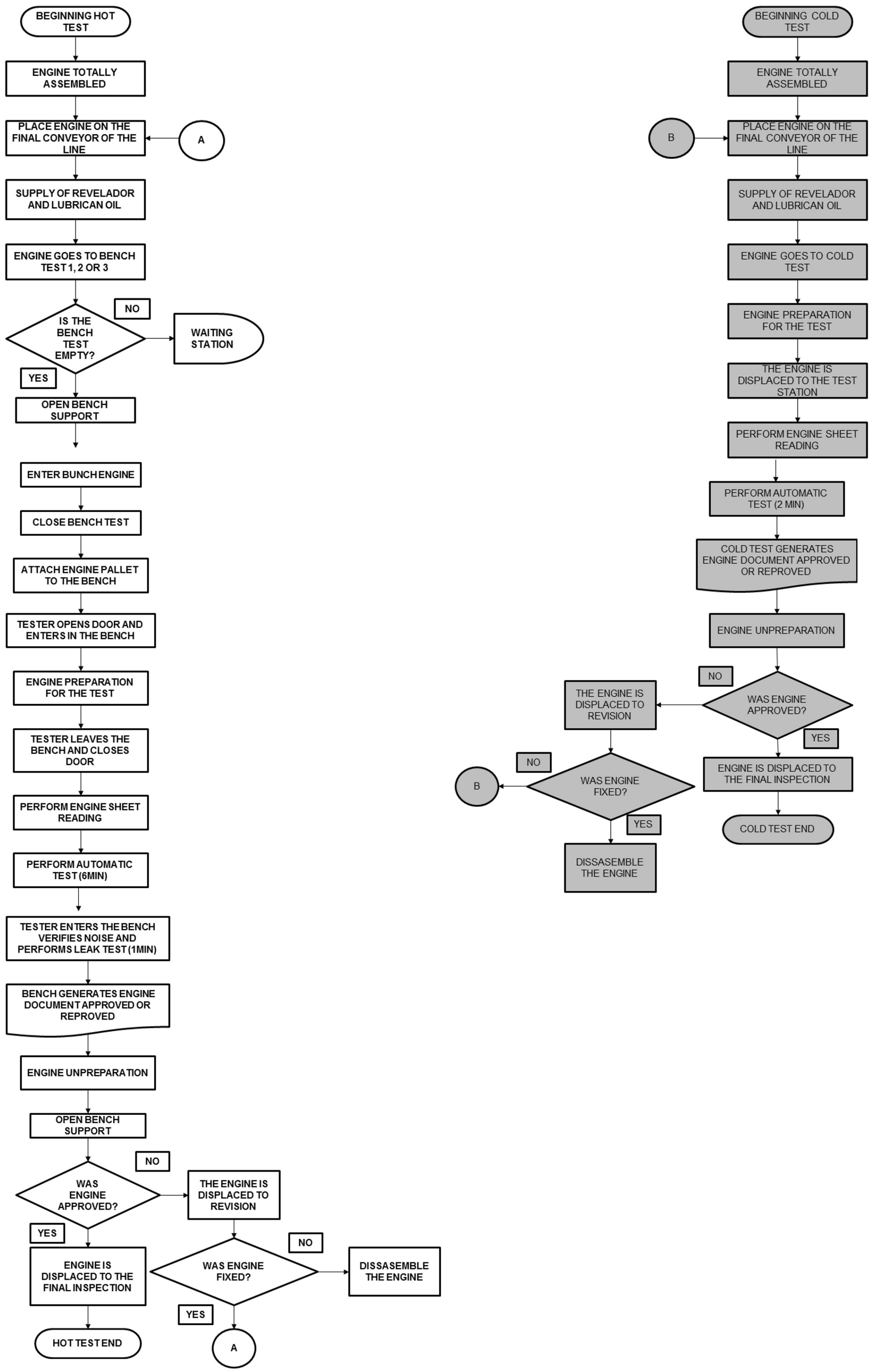

Figure 1. Comparison of the processes Hot test and Cold Test.

and verification of noise also aggregate time and activities to the flowchart of the Hot Test.

The preparation of the Cold Test is done quickly through connections of quick couplers, and the placement of the slave steering wheel, which is the activity that requires more time. The dieses supply is minimum, as the quantity is also minimum, 0.092 liters by engine. This time of supply is contained in the automatic cycle of Cold Test.

In the unpreparation a gain is noticed in the Cold Test process flow, because when the tester "A" unprepared an engine the tester "B" is already running another test. Unlike the Hot Test process that each bench has its tester and can only enter another motor in the bench when it is unoccupied.

Effectiveness of the processes i.e., the extent to which the process meets the needs and expectations of customers, demonstrating its quality (Gonçalves, 2000), the indexes PPM (parts per million) of two processes will be compared. The example will be one month AT random, but it is understood that the numbers on average repeat.

Table 1 of Hot Test process shows a total of 27,192 engines defective per million tested in the test bench. Even though this is a process that has been used and perfected since 1996 in this company. Table 1 presents the results of parts per million (PPM) of the bench tests in a given month of 2014.

The main flaws detected in the Hot test are the leaks. The biggest challenge for this process is not in its own assembly line, because 95% of the causes of the problems of leaks are in the parts supplied by third parties.

In the same month of 2014, the index PPM was checked in Cold Test process as shown in Table 2, equal to 662 PPM. Table 2, PPM Cold Test prove such figures.

The cold test is directed more to detect failures in the process, being possible to identify parts exchanged, parts with defects and failures along the assembling. Some actions in the course of the assembly line are implemented for the solution of problems, i.e., return to the previous proceedings attacking the causes.

Table 1. PPM Test Benches.

Descriptions	BT 01	BT 02	BT 03	Total
Production	1,093	1,048	801	2,942
Rejections	31	32	17	80
% of Rejection	3%	3%	2%	2.72%
PPM	28,362	30,534	21,223	27,192

Table 2. PPM *Cold Test.*

Description	CT 01
Production	3,022
Rejection	2
% of Rejection	0.07%
PPM	662

It is realized that the Cold Test has a PPM index much better than the Hot Test. However, when the Cold Test was built, it did not include the tests for leaks and engine turbine. Thus, these defects are detected only at Hot Test considerably increasing its index.

The two processes meet the customer expectations, since the problems are identified in the assembly line, even before the engines being sent to the customer. The proof of the effectiveness of the two processes working together are the records of only two failures in the client, including the years 2012 and 2014.

Efficiency of the processes: this item measures the resources invested in the process and the right way to produce an output according to the required quality (Gonçalves, 2000). It is verified a major advantage of the Cold Test over the Hot Test, as shown in Chart 1. The measured resources were the productivity, the noise level, use of effluent treatment, electrical power, compressed air, chilled water and fuel consumption.

Analyzing Chart 1, starting with the measurement of productivity, it is perceived that a Cold Test machine is 3.7 percent more efficient than the three tests benches (Hot Test).

The noise level is a measured item that affects both for the human being, as for the investments, especially in the construction of test benches. If the bench tests were not enclosed rooms, the workers would only be exposed to 103 dB for a maximum period of 45 minutes, as described in NR-15. In *Cold Test* process the noise of 61 dB being smaller than the entire assembly line which is 86 dB, therefore this machine does not need to be enclosed.

There is reduction of specialized workforce in the Cold Test, as shown in Chart 1. When accounting for the two shifts Hot Test has two testers more than the Cold Test, being a tester per bench (6 persons) against two testers of Cold Test (4 persons).

The reduction in the cost to maintain a Cold Test process is remarkable in comparison to the Hot Test. The Cold Test does not use resources, such as: sewage treatment, chilled water and its consumption of diesel is 93% smaller than the Hot Test process. The compressed air and electricity consumed are the only resources used in the two cases. Cold Test is much more benign to the environment in comparison to the Hot Test, since it has less natural resources in its process.

4.2 Processes analyses

The operation of the Bench Tests, employees on the production line is based on the performance test, aligned as described by Pereira (2009), being performed with speed variation and testing of loads, determining the engine power. In this test the parameters of torque, speed, temperatures and pressures required for the validation of the engine

Chart 1. Comparison of efficiency in the two processes.

Resources measured	*Hot Test*	*Cold Test*	Comparison	Advantage
Productivity (Irog Global)	76.50%	80.20%	One piece of Cold *Test equipment* produces 3.7% more than three Tests benches (*Hot Test*).	*Cold Test*
Noise Level	103 dB	86 dB	*Hot Test* process needs to be enclosed, as according to NR-15 annex 1, its noise exceeds the minimum of 85 dB for 8 hours of work per day.	*Cold Test*
Treated sewage	Yes	No	*Hot Test* needs treated sewage in order to prevent leaks	*Cold Test*
Workforce	6 people	4 people	*Hot Test* needs 2 extra testers then *Cold Test*, accounting the 2 shifts.	*Cold Test*
Electric energy	Yes	Yes	The two processes need electrical energy	The same
Compressed air	Yes	Yes	The two processes need compressed air	The same
Chilled water	Yes	No	*Hot Test* process needs water from Chilling towers for their dynamometers.	*Cold Test*
Average fuel consumption	1.27 L/ engine	0.092 L/ engine	The average consumption in the Cold Test is 93% smaller than the Hot Test. Every 14 engines supplied in the Cold Test 1 engine is supplied on the Hot Test.	*Cold Test*

are verified. The authors Ferguson & Kirkpatrick (2015), also highlight the needs of the analyzes of combustion and emission of gases.

Comparing the practice with theory studied there is a disagreement in the detection of leaks. Martyr & Plint (2012), describe the need for a special station (Black-light) for the detection of leaks. In the company there is not a *Black-light,* simply the tester turns the lights off of the bench and checks for leaks with a lamp of the type black light.

The processes analysis consists of comparing the following attributes: (A) the number of people involved in the process; (b) approval levels; (c) administrative processes involved; (d) the cycle time; (e) the complexity (Harrington, 1993). Chart 2 shows all these criteria and compares them with each other.

Number of people involved: the number of people involved in the Hot Test process is higher due to the need of the operator of the cooling tower. The bench tests require water for the cooling system of the engine and the dynamometers. The effluent treatment station also has an operator, in charge of the sewage treatment issued by each bench test. There are also two testers in the Hot Test.

Administrative processes: For the administration of these two processes activities in parallel are necessary to production aimed at guiding and facilitating the work on the factory floor. It is understood as administrative processes the activities involved for which each process performs its functions in the most appropriate way.

The operator of the Utilities sector also makes the fuel management, operating in the tanks pumps operation, receiving the fuel and making the consumption control. The fuel consumption burdens even more the Hot Test process, because the banks consume 93% of fuel more than the cold test. The documentation of the processes control is another item which adds more value to the Hot test, since it will be necessary to multiply by three tests bench. The tests bench has exit to the sewage, as leaks are common during the

Chart 2. Comparison of criteria for the processes identification.

Identification criteria	*Hot Test*	*Colt Test*	Comparison	Advantages
Number of persons involved	12	8	The process *Hot Test* adds two more testers, an operator of Chilling Tower and a wastes treatment operator.	*Cold Test*
Administrative processes	Yes	Yes	The Hot Test presents much more administrative processes, such as: control of water, management of fuel, environmental control on emissions and sewage treatment, documentation of the process is multiplied by three (Bench).	*Cold Test*
Cycle Time	7 min.	2 min.	The time of the automatic cycle of the Cold Test is 3.5 times faster than the Hot Test.	*Cold Test*
Complexity	Yes	Yes	The Cold Test is more complex due to the fact that it performs more tests that the Hot Test and is a new process in the company.	*Hot Test*
Approval levels	11	15	*Cold Test* has 8 levels of approval ahead and 7 equal comparing to Hot *Test*. Hot Test has 7 levels ahead and 3 Equal comparing to the Cold Test, but the Cold Test does not detect leaks	Doubt

test. The effluent goes to the central treating facility where there is an operator in charge.

Cycle time: The cycle time has already been treated previously with setup tasks, and then it is compared only the automatic cycle time, that is, the engine is already prepared for the test and the operator activates the beginning of the cycle. The time for the implementation of the automatic cycle is one of the great advantages of Cold Test, because it is 3.5 times faster than the three tests bench (Hot Test). In the article of the authors Delvecchio et al. (2007), it is also confirmed this considerable reduction of time, because in its comparison the Hot Test takes 12 minutes and the Cold Test runs 2 minutes to the cycle in Automatic.

Complexity: The criterion complexity is something difficult to be measured. However, when analyzing the two processes, it is notice that the operators from both the cold and the hot are the most capable of the cold and the hot are the most capable of assembly line. The schooling issue is an important requirement, since that all the testes from both processes have the technical high school. However, it can be concluded that the Cold test process is more complex, due to the fact that it doing more tests and requiring more interpretative capacity, than the hot test. Besides being a newer process, in which the operators are not familiar with. *Hot Test* has testers with 18 years of experience, whereas in *Cold Test* the operators have at the most three years of experience.

Levels of approval: it is understood as levels of approval the tests executed so that the engine is ready to be assembled in the vehicle, that is the engine is approved. So that the engine is ready to be approved in the Hot test, for example, it must be exempt from any type of leak, it needs to reach minimum and maximum speeds (RPM) in the process steps, according to specific loads of the project, proving thus its power.

In the Hot Test the temperatures and pressures of the lubricating oil, diesel oil, inlet and exhaust are controlled. There are specific appliances, such as, *Blow By Meter* and *Smoke Meter* to approve respectively the internal pressure of the oil and the engine smoke levels.

Cold Test is a dynamic test, because its measurements are still in the course of the cycle and the Hot Test is a static test, since its measurements are given in specific points of the test. As the rotation of the cold test is very low (80 to 1,000 RPM) when compared to the Hot Test (800 to 3,600 RPM) the comparison is impaired, because the engines are operating under different conditions.

Chart 3 shows the comparison of the levels of approval, item by item identifying the column condition, advantage, disadvantage or equality between the two processes.

The considerable compatible tests in two processes are: electrical testing, oil pressure test, exhaustion test, test of torque, starting torque and torque and oil pressure. The *Rail* pressure test consists of a precise monitoring during the whole cycle in the Cold *Test,* since that in the *Hot Test* it is only tested the *Rail* sensor.

The oil pressure test HS (High Speed) is achieved on both tests, however problems in lubricant oil pressure in the Hot Test process usually damages the engine, whereas in the Cold Test there is no such risk.

Chart 3. Comparison of the levels of approval of two processes.

			Approval levels *Hot Test*	**Condition**
			Electric test	**Equal**
Condition	**Approval levels *Cold Test***		Leaks of diesel, water, oil, exhaust and intake systems.	**Advantage**
Equal	Electric test			
Advantage	Rail pressure			
Advantage	Injectors test		Engine power test	**Advantage**
Advantage	Vibration test 01		Noises: head, turbo, internal, intake and exhaust.	**Disadvantage**
Advantage	Vibration test 02			
Advantage	HS oil pressure test		Lubricant oil temperature and pressure	**Equal**
Equal	Synchronism test *CAM*	**X**		
Equal	Synchronism test *CRANK*		Exhaust pressure and temperature	**Equal**
Equal	Exaust test			
Advantage	Intake test		Water pressure and temperature	**Advantage**
Equal	Oil pressure test			
Advantage	Torque test		Cooler (turbin) pressure and temperature	**Advantage**
Equal	Starter torque			
Equal	Oil pressure and torque		Vaccuum pressure	**Advantage**
Advantage	Diesel system test		Internal pressure (*Blow By*)	**Advantage**
			Smoke Meter	**Advantage**

Synchronism tests *CAM* and *CRANK*, in *Cold Test* and the command and crankshaft synchronism are constantly monitored during the test, doing a scan of 360°, whereas on the Hot Test these sensors are monitored only in the fuel injection points.

The vibration tests 01 and 02 of Cold Tests are compared to the noise test of Hot test. It can be considered more advantageous the Cold Test, because it is a qualitative measurement (measurement of two accelerometers) and on the Hot Test it is subjective (depends on the experience of each tester).

The tests only performed in Cold Test are: admission test, system test of diesel, injector tests, where each injector is monitored and compared to its standard curve for subsequent approval.

The tests only practiced in the Hot Test are: pressure and water temperature, pressure and temperature of the cooler (turbine), vacuum pressure, internal pressure test (Blow by), Smoke Meter test or smoke test. The leaks test ends up being a great differential, as there are no leaks at the Cold test. Finally, the power test is only practiced at the Hot test, as the rotation is monitored regarding the corresponding load (torque) in each step of the test, and thus it is approved or reproved in function of its power.

4.3 Processes implementation

To operate the Cold Test new employees were not hired, but rather employees with higher level of education and experience in the assembly line were used. Portable special equipment and weights were purchased for the calibration of pressure transducers, load cell and analogue sensors. The main spare parts of the machine were also purchased.

After the complete connection of the machine, a pilot test was implemented in accordance with the Thyssen Krupp (2011), where 5% of the production of engines passed the Cold Test before the Hot Test. Thus fine adjustments were performed in the control parameter, in order to validate the process for the complete implementation, test 100% of the engines. This pilot test was executed during three months until it is totally released and disseminated to the production.

4.4 Processes maintenance

The maintenance processes are performed through a daily monitoring. The two processes have spreadsheets containing information about each engine that is tested. These spreadsheets contain information that helps to understand and control possible variations, making it a feedback system to the processes. There is also a system of traceability where the data of each engine tested automatically in the factory are stored.

The monitoring of information is in agreement with the theory studied in Antunes (2009) and Antunes et al. (2013), because they are accompanied not only by the testers, but also by the operational technicians, processes technicians, process engineers and the maintenance sector of the facility. Since that these two processes are considered basic for the company. All this control and follow-up have as an aim to assure the efficiency and efficacy of the two processes.

In each case there is a computer with a spreadsheet, called logbook, containing information related to the shift turn, tester, engine serial number, downtime diagnosis, observations related to the electric wires (NOK Test - specifies the electrical malfunction), the result of the tests, observations and time of engine downtime, date, time, and shift of the test, consumption of diesel, description of rejection or correction, type of downtime and observations of downtime. All this information is collected from each engine that is tested in the Hot and Cold test. Based on this information, the engineer of each process investigates the causes of rejections and performs the actions to solve the problems, controlling daily the process.

5 Final considerations

The processes were mapped, analyzed and inserted in a same basis facilitating their understanding. Relationships with the theoretical referential and evidences were identified that the Cold test has great advantages when compared to the Hot test.

Despite of the *Cold Test* showing several benefits in its process, important requirements of Hot test approval, such as, leaks and test in the turbo compressor, are not identified in the Cold Test. That is why the Hot test has better reliability and, consequently, better advantage. The Cold Test prevents the company from not having process defects (bolts without torque, lack or exchange of components) in the validated engine, fully assembled. Such conclusions bring the idea of complementarity of processes.

The flaws at the turbo compressor were not detected, because the same in only assembled after the engine goes through the Cold Test. Theoretically the turbo compressor should have full supplier warranty, since that the Cold test studied was not set up to test the engine with turbo compressor.

Responding to the research question, the Cold test cannot replace totally the Hot test, but the tests are complementary. Even because, the Cold test is not able to detect leaks and test the operation of the set turbine of diesel engines. Studying such items not listed at the cold test, it was concluded that they could have been incorporated. Everything indicates that they were not introduced, perhaps because of inexperience of people involved in the project scope or due to matters involving costs.

Despite of these problems, the Cold test proved to be a sustainable test, as it fulfilled with three pillars of the concept Triple *Bottom Line* (Elkington, 1997), divided into economic, human and environmental aspects. Regarding the economic aspect, the Cold Test increased the financial gains of the company providing agility and lower cost. Concerning the human aspect, the process decreased the risks of accidents and the noise which the employees are exposed to. And when it comes to environmental aspect there are better gains, since that the process does not use water, decreases the consumption of fuel to a great extent, avoids the emission of pollutant gases and the pollution of effluents compared to Hot test.

Several bodies of research can be performed, one of them to respond jointly, about the real importance of involvement and joint work of the whole productive chain for the proper development of the Cold test process. One comparison of the implementation costs of the processes Hot test and cold test. One remark of the economic point of view of the two processes. And finally, a study on the environmental impact in the exchange of one Hot test process to a Cold test process.

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