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USING A TOTAL QUALITY STRATEGY IN A NEW PRACTICAL APPROACH FOR IMPROVING THE PRODUCT RELIABILITY IN AUTOMOTIVE INDUSTRY

Abstract: *In this paper a Total Quality Management strategy is proposed, refined and used with the aim at improving the quality of large-mass industrial products far beyond the technical specifications demanded at the end-customer level. This approach combines standard and non-standard tools used for Reliability, Availability and Maintainability analysis. The procedure also realizes a stricter correlation between theoretical evaluation methods and experimental evidences as part of a modern integrated method for strengthening quality in design and process. A commercial Intake Manifold, largely spread in the market, is used as test-case for the validation of the methodology. As general additional result, the research underlines the impact of Total Quality Management and its tools on the development of innovation.*

Keywords: *total quality, reliability, FTA, FMECA, design for experiment, accelerated life tests, intake manifold*, *inlet manifold*

1. Introduction

1.1 Toward the global market

The global competitiveness on the 21st century markets is feeding a continuous technological progress with new generations of technology and products, with higher capability of intensive productions and with a general raising in buyers' demand and expectation for quality.

Nowadays, quality cannot be reduced just only to reliability performances, but it is a merging of different factors between technological aspects and clients' satisfaction (Sailaja *et al*., 2014). Companies need to constantly improve their products and offering in order to stay competitive (Gidey *et al.*, 2014): so the cycle of life of designing, developing and manufacturing a new product requires being shorter in time and, even, lower in cost. But, at the same time, the quality level (in the meaning of reliability, safety, functionality, etc.) should not to suffer by the reduction of resource (time and cost).

Every industrial company, covering a position of leaders in every specific field of technology, is inexorably pushed toward a high level of technology, only achievable using an integrating approach for quality improvement.

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1.2 Total Quality, ups and downs

The Total Quality Management (TQM) is a philosophy that emerged in the U.S., in the ‘60 of the last century, as explanation of the industrial and commercial success characterizing American companies at that time. Probably, these terms were used for the first time by an American scientist, A.V. Feigenbaum, in his book published in 1961 with the title "Total Quality Control”, and, then, quickly widespread all over the world. But, considering the relevance of the argument, not everywhere these concepts were implemented at the same level. In the late 1970s and early 1980s, the developed countries of North America and Western Europe suffered economically in the face of stiff competition from Japan's ability to produce high-quality goods at competitive cost. Firms began re-examining the techniques of quality control invented over the past 50 years and how those techniques had been so successfully employed by the Japanese. It was in the midst of this economic turmoil that TQM took root.

As general note, TQM consists of *organization-wide efforts to install and make permanent a climate in which an organization continuously improves its ability to deliver high-quality products and services to customers*.

TQM enjoyed widespread attention during the late 1980s and early 1990s before being overshadowed by ISO 9000, Lean manufacturing, and Six Sigma. Currently, a special attention to TQM is re-emerge, in consideration of the relevance of its general concepts.

After more than half century, the modern approach to the Total Quality (TQ) highlights *customer satisfaction* as, doubtless, the primary key-factor for a stable commercial success and shows that every business has four main goals which are :

- Customer satisfaction,
- Competitive advantage in terms of customer satisfaction,
- Long retention time
- Gaining larger market.

1.3 TQM inside a general strategy of developing

In line with this philosophy, TQM embraces all the activities that organizations use to direct, control and coordinate quality. These activities include formulation if a quality policy and setting quality objectives. According to the literature review, it could be stated that achievement of quality objectives leads to improvement of the competiveness, effectiveness and flexibility of a company. This is a important reason why the considered problem has become a topic of research for both industry and academia in the last decades (Krivokapic *et al*., 2013).

The quality goals and objectives could be considered as part of the strategic goals and objectives. Identifying and defining strategic objectives and strategies of the organization are included in the strategic approach to managing manufacturing companies. It is based on a continuous process of constant adaptation manufacturing companies to a variable environment. Strategy subsystem defines ways to address future situations and problems. In order to manufacturing company achieves its goals is not enough just to has formulated a strategy, it is necessary to implement the strategy in all operational and budget plans and continuously improve. Performance and quality measurement is an essential element of effective planning, improvement and control as well as decision making. The measurement results reveal the effects of strategies and potential opportunities (Bhagwat and Sharma, 2007).

The establishment and implementation of TQM approach in a dominant number of literature sources is described as a precondition for achieving sustainable business systems. The prerequisite for this is that the quality management is implemented on the basis of *measurable parameters*, and that the mechanisms for continuous testing and review are constantly promoted. A positive correlation between TQM approaches and innovation is considered by many literature sources and research. Also, continuous improvement and innovation are the core values of TQM concept. Research suggests that in terms of company innovation, knowledge development represents the priority. The examples indicate that continual improvement in certain conditions, lead to fast innovations in products and organization (Krivokapic *et al*., 2013).

1.4 TQM and its variety of instruments

While there is no widely agreed-upon approach, TQM efforts typically draw heavily on the previously developed methods and tools of quality control. Part of these well-known instruments refer to the management process and aim at the realisation of an efficient Quality Management System (QMS) supporting the implementation of Total Quality as a whole (Nestic *et al*., 2013). QMS represents a collection of business processes focused on achieving your quality policy and quality objectives (organizational structure, certifications, policies, procedures, processes and resources needed to implement, etc.).

On the contrary, some of TQM techniques can be considered *less general* respect to what generally included inside the QMS, and more related to the fundamental steps of design and validation of quality products. These tools refer to well-defined aspects of product engineering as reliability, availability, safety, mantenability and other technical concepts (Figure 1.).

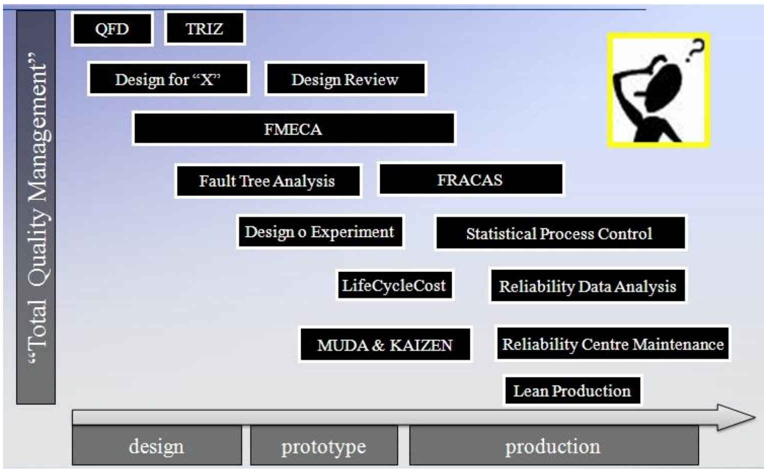

Figure 1. Tools and methods for a Total Quality Management

Design of Experiments (DOE), *Analysis of Variance* (ANOVA), *Failure Reporting, Analysis, Corrective Action System* (FRACAS), *Failure Mode Effect Analysis* (FMEA), *Fault Tree Analysis* (FTA), *Reliability Analysis* of in-service failure Data (RDA), *Validation Procedures* or *Accelerated Life Tests* (ALT) are theoretical methodologies or practical tools to be used inside an approach of Total Quality Management (Al-Najjar *et al*., 1996) even if not specifically mentioned inside the QMS.

2. Problem Statement

2.1 Aims and goals

This research, realized with the support of *Magneti Marelli*, a global leader in control engine technology, aims at creating a convincing methodology for the prediction and validation of reliability of automotive components far beyond the experimental limits of accuracy. In fact, experimental and validation tests are a fundamental practice for improving the reliability and the functionality of mass-oriented products. But, since the high level of quality of modern commercial components, *validation tests* have to be properly integrated by advanced tools for reliability deployment based on failure models and statistical evaluations, as here detailed.

This methodology is developed in accordance with the Total Quality (TQ) principles and, specifically, integrates the above-mentioned TQ instruments (FTA, FMECA, RDA, etc.). This paper also includes a detailed description regarding the *experimental strategy* used to provide physical evidences of quality targets achieved. This methodology is verified and here proposed on a specific automotive system that plays a central role for all the functionalities of the vehicle, an Intake Manifold, but can be used to direct improvements in quality, safety and reliability for several industrial products (Fragassa, 2009).

2.2 Guarantee of Quality

The Guarantee of Quality was born more than 30 years ago inside of manufacturing companies for avoiding errors of workers that appeared on the end of production line, with the basic aim to reduce rejected products increasing the productivity. And today, using high advanced processes, an accurate control chart monitoring and a proper methodology of design for manufacturing, large companies are able to guaranty an industrial reliability close to 100% at the end of their production line (less than 5PPM of failures in the case of automotive industry).

For further improvements in reliability, it is necessary to move the attention from the quality of process to the quality of product verifying the conditions (usage, environmental, etc.) for which a system, even if correctly manufactured, could present a statistically relevant failure during the working period. The actual level of reliability, warranted by the main enterprises active in automotive field, are for products with 0.6 IPTV (incidents per thousand vehicles per year) but the threshold is falling down very fast year after year. Explicit clauses in business to business contracts define this limit and major penalties if the goal is missed. To avoid transforming every commercial trading in a legal dispute, every company needs to develop a justifiable methodology for reliability estimation starting from experimental procedures and results.

2.3 TQM inside the Life Cycle Assessment

Magneti Marelli, a company inside FIAT Group, is an international leader in design and production of high-tech components and systems for automotive industry. In particular the Powertrain Division develops and produces integrated engine control systems and integrated driveline systems for cars, commercial vehicles and motorcycles. These mechatronic devices are advanced in terms of performance and quality. Constant attention aimed at meeting the customer's requirements as well as a proactive approach to propose technical solutions of quality excellence. In particular, the company is specialized in the supply of assembled and tested modules in order to reduce time to market and improve quality. Quality results are mainly guaranteed by the solid TQ methodology used as driver for product and process developments. Specifically, this integrating approach for quality improvement (Figure 2) involves 6 *teams/key experts* (e.g. Product Engineer, Product Manager, Plant Manager, etc.).

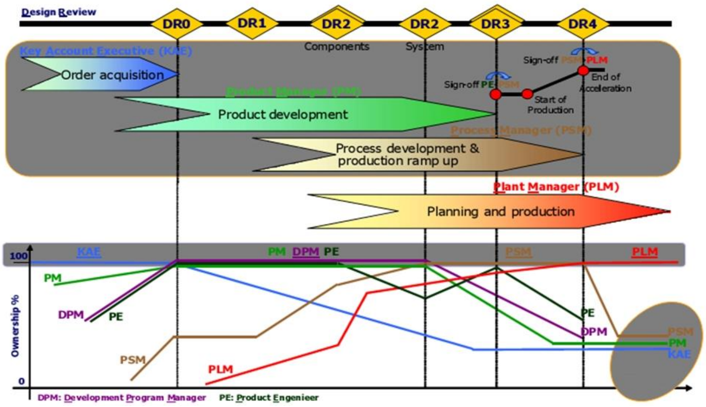

Figure 2. Total Quality approach scheme in the Life Cycle Assessment

They work together in a sequel of 4 technical phases (e.g. Product Development, Process Development, etc.) and 5 Design Reviews (DR).

3. Using the TQ Approach

3.1 System Definition

A first demonstration of the improvements permitted by the application of a TQ methodology during the phase of component design and developing was realized on a Diesel Air Intake Manifold, entered into production some years ago and now running on the market in dozens of millions of samples *(Mod. CAD 241 and 247)*. An intake (or inlet) manifold (Figure 3) is the part of an engine that supplies the fuel/air mixture to the cylinders.

Figure 3. Air Intake Manifold

In contrast, an exhaust manifold collects the exhaust gases from multiple cylinders into one pipe. The primary function of the intake manifold is to evenly distribute the combustion mixture or just air in a direct injection engine to each intake port in the cylinder heads. Even distribution is important to optimize the efficiency and performance of the engine. It may also serve as a mount for throttle body (Figure 4), fuel injectors and other components of the engine.

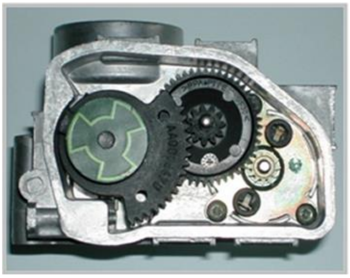

Figure 4. Throttle Body

This system, in connection with the combustion chamber, creates a flux of air toward the engine adjusting the quantity by its throttle body. The Intake Manifold contains a variable swirl actuator (Figure 5), an electrical device driven by ECU (Electronic Control Unit), used to control the throttles inside each air duct. Main structural components of the air intake manifold assembly include: main body, gaskets, throttle valves and hang-on components.

Figure 5. Variable Swirl Actuator

The intake manifold also carries out the function of integrating other engine supply control functions: fuel supply, fuel anti-evaporation system control, and engine operation point control. Hence, the air intake manifold can also carry out the function of engine supply mechatronic module, with the following advantages: compact size, cost, and assembly on the engine. The intake manifold basically consists of a volume of thermoplastic material with high thermal and mechanical resistance, hooked up to the engine by means of duly sized conduits and made in injection moulding technology and welding of vibrating parts. The intake manifold was usually manufactured in aluminium casting process with little arrangements in plastic, but, to reduce weight and the connected fuel consumption, plastic is gradually replacing aluminium where permitted by security requirements and by the complex shapes. The technical solutions satisfy needs in terms of weight reduction and recyclable material, but the new era of manifolds made in plastic obliges a strict attention on improving reliability and safety of automotive components.

3.2 General Methodology

After dividing the complex system, as the intake manifold, in its basic parts and deploying a deep comprehension of relations between parts and system's functionalities, the integrated approach follows the steps of:

1. State-of-art: using specific datasheets and other information from the scientific literature a quick, but approximate evaluation of reliability was performed; starting from the estimated MTTF, by proper correcting parameters, a satisfactory value for failure rate can be obtained;
2. Suppliers' data: requiring additional reliability information to the suppliers about durability of specific parts or other critical aspects, a better accuracy in prediction can be obtained; this action plan permits transferring an unambiguous and detailed know-how from suppliers;
3. On-field data: acquiring information from customer service about criticalities, failures, maintenance tasks, guarantee costs, but also about use (e.g. mileage per year) and misuse a better comprehension of reliability behaviour in like-real conditions is possible; by a relatively low amount of data (failure times), accurate models for reliability can be drawn;
4. Simulations: focusing on critical components or specific situations, FEM tools can be used to compare different physical aspects increasing the knowledge for design or process; critical interactions between components can be easily investigated;
5. Experiments: looking into precise samples and significant conditions of loads, either by standard testing machines or pioneering equipments, experimental evidences and confirmations can be obtained; accelerated tests also permit to predict far away failure conditions even for highly reliable systems (Massimo *et al.*, 2006)
6. Model developments: merging all the previous information models for

damage predictions can be developed; since the resources needed, this deep and laboured level of comprehension on reliability aspects is justified only for few situations.

3.3 Reliability Early Estimation

As first step in (re)Design for Quality, a quick prediction for system reliability was obtained by using failure data from the "state of art". This kind of information are available in professional databases (Mahar *et al.*, 2011, Denson *et al.*, 1997) as failure rates referred to the most common mechanical and electronic components (Figure 6).

These values, usually expressed as *n. of failures* on "*running unit*" (typically hours or km), were measured and collected by past experiments. They can be used as a preliminary estimation for components under investigation.

Specifically, the reliability of every single component inside the system (more than forty in the case study) was daftly estimated using these values together with standard corrective factors (e.g. factor of usage). Reliability of whole assembly was also evaluated by a FTA methodology.

Part Description	Quality Level	App Env	Data Source	Fail Per E6 Hours	Total Failed	Operating Hours (E6)
Actuator,Mechanical (Summary)				25.970684		
	Commercial	AUC		35.409040		
	Military	ARW		< 4.289581		
	Unknown			21.514077		
		A		57.956000		
		AUT		5.109966		
		GM		33.624183		
Actuator, Mechanical				6.849986		
	Military	ARW		< 4.289581		
			221006-000	< 37.782899	0	0.026467
			221007-000	< 37.194079	0	0.026886
			221008-000	< 37.170576	0	0.026903
			221009-000	< 39.215686	0	0.025500
			221010-000	< 36.919442	0	0.027086
			221011-000	< 35.527765	0	0.028147
			221012-000	< 37.770056	0	0.026476
			221013-000	< 40.701697	0	0.024569
			221014-000	< 47.418085	0	0.021089
	Unknown			13.107953		
		AUT	18459-000	5.109966	1	0.195696
		GM	18459-000	33.624183	2	0.059481
Actuator, Mechanical,Linear				41.729409		
	Commercial	AUC		35.409040		
			NPRD-090	227.829075	1061	4.657000
			NPRD-098	5.503249	83	15.082000
	Unknown	A	14182-001	57.956000	-	--------

Figure 6. Example of part entries as available from States of Arts

These results, mainly related to literature data, cannot be used for an accurate demonstration of reliability since:

1. The failure data available in literature normally come from experiments realized in different conditions respect to the working conditions for the real system (different components, loads, environments, etc.)
2. The reliability behaviour of the whole system is defined by the particular structure of functional connections between each component (Fault Tree Analysis)

but these first evaluations are fundamental for the following steps (Figure 7).

Nomenclature	Description of components	Quantity	RAC Confidence of the literature data: L-Low M-Medium H-High				MAGNETI MARELLI-SUPPLIER EXPERIENCES					
			R-Reliability	F=1-R	ppm	Rang	R-Reliability	F=1-R	ppm	ppm FTA	R-FTA	Comment
1	MACHINE BORE	1	0,999760516	0,000239484	239,4837352	TL	1	0	0	0,20	0,999999801	0 ppm field
2	SHAFT	1	0,999977106	2,2894E-05	22,89397793	M	1	0	0	0,07	0,999999929	0 ppm field
3	GEAR	1	0,999907712	9,22881E-05	92,28814619	L	1	0	0	0,03	0,999999966	0 ppm field
4	ANTENA	1	0,999948489	5,15107E-05	51,51071328	L	1	0	0	0,06	0,999999939	0 ppm field
5	GEAR HOUSING	1	0,990613529	0,009386471	9386,47084	L	0,999995	5E-06	5	0,10	0,999999896	< 5ppm field
6	BRONZE BUSHING	1	0,995189921	0,004810079	4810,078665	M	1	0	0	0,00	1	0 ppm field
7	GEAR HOUSING COVER	1	0,993307168	0,006692832	6692,831927	M	0,999955	4,5E-05	45	0,33	0,999999675	new solutioin
8	GEAR BOX SEAL	1	0,999997138	2,86178E-06	2,861775905	TL	0,999997	3E-06	3	0,03	0,99999997	new solutioin
9	ROLLER BEARING	1	0,999891544	0,000108456	108,4555803	M	1	0	0	0,03	0,999999975	0 ppm field
10	DOUBLE PINION	1	0,999907712	9,22881E-05	92,28814619	L	1	0	0	0,04	0,999999964	0 ppm field
11	DCM SPRING	1	0,998562463	0,001437537	1437,537201	M	1	0	0	0,00	1	0 ppm field
12	TORSION SPRING	1	0,995917299	0,004082701	4082,700623	M	1	0	0	0,14	0,999999861	20 ppm field
13	ELETRICAL MOTOR DC	1	0,993627248	0,006372752	6372,752305	M	0,9999	1E-04	100	0,27	0,999999727	< 100 ppm field
14	GEAR	1	0,999907712	9,22881E-05	92,28814619	L	1	0	0	0,03	0,999999966	0 ppm field
15	DOUBLE PINION PIVOT	1	0,999839839	0,000160161	160,161101	H	1	0	0	0,05	0,999999955	0 ppm field
16	CAP for PIN	1	0,99952109	0,00047891	478,9101179	M	1	0	0	0,05	0,999999947	0 ppm field
17	IDLE SCREW CAP	1	0,99880166	0,00119834	1198,340449	M	1	0	0	0,00	1	0 ppm field
18	AXIAL PLAY PIN	1	0,999985333	1,46665E-05	14,66651495	H	1	0	0	0,19	0,999999813	0 ppm field
19	GLASS CAP	1	0,99952109	0,00047891	478,9101179	M	1	0	0	0,14	0,999999865	0 ppm field
20	SCREW_FIXSING MOTOR	2	0,999649774	0,000350226	350,2255651	H	1	0	0	0,00	0,999999999	0 ppm field
21	SCREW_FIXSING VALVE	2	0,999649774	0,000350226	350,2255651	H	1	0	0	0,01	0,999999992	0 ppm field
22	IDLE SCREW	1	0,999649774	0,000350226	350,2255651	H	1	0	0	0,00	1	0 ppm field
23	SCREW FOR FIXING BORE	4	0,999649774	0,000350226	350,2255651	H	0,999995	5E-06	5	0,00	0,999999999	new solutioin
24	THROTTLE VALVE	1	0,999513616	0,000486384	486,3842768	L	1	0	0	0,03	0,99999997	0 ppm field

Figure 7. Part entries as implementated by the integrated method

3.4 Matrix of Criticality and FTA

In the second step, the main functions were recognized. Each function was divided in different sub functions and addressed to each component creating a correlation matrix ("function vs. component") that gives several useful information like:

- how many components are in the same sub function
- how many functions belong to each single component

In the example, the main body of intake manifold has 13 functions and, considering the total number of functions (=56), it represents one of the most critical single-components for the whole system.

Using the previous evaluation of reliability for every component and an FTA approach (IEC 61025, 2006), it was possible to calculate the reliability for the main and sub functions combining the contribution of every component that participates in them. On the end it was calculated the reliability of the main functions.

The FTA method permits to take in count the logic and functional connections between components and leading to the general "top event" of failure (at the level of system) when single events of failure occur at the level of parts.

3.5 FMECA Analysis

As third step, another standard tool of Design for Quality, specifically the Design Failure Mode and Effect Analysis (IEC 60812, 2006), was used to define the *gravity*, an important standard parameter able to indicate the criticality of each functions.

For example, during this step, as the most critical functions on Diesel Intake Manifold, were recognized:

- resistance on anhydride sulphurous
- resistance on thermal shock
- resistance on vibration / temperature
- resistance in resonance conditions

After this evaluation process, 5 different TQ indicators for evaluation of criticality were available:

- experimental reliability for components (according to the state of art)
- experimental reliability for main functions or sub functions (according to the state of art)
- grade of complexity of functions
- grade of interrelation of components
- standard index for gravity of functions.

Using these indicators, critical functions and critical components were highlighted in a quick and objective way, creating a roadmap to distinguish which component has to be experimentally tested in order to improve the reliability of each critical function. In this way, it is possible to limit the number of components to investigate, reducing time and cost for experiments.

3.6 Application of Users' profiles

Considering that the TQ methodology here proposed aims at experimentally validate the reliability of systems during an ordinary usage, it is necessary to create a strict correlation between "literature data" (already available), experimental conditions (of future validation tests) and all the information coming from clients referring to real use of components. Some of the information from customers are available in the company by different formats (e.g. mission profiles, technical requirements, contract qualifications, etc.) or acquirable from the clients by the guarantee & support service (e.g. failures modes and distributions, etc.).

Specifically, the Diesel Intake Manifold is contractually designed for a mission of 10 years, 250.000 km, running at an average speed of 34 km/hour with particular mechanical, thermal and vibration loads, in specific environmental conditions (as humidity, dust, etc.).

Once decided which functions are critical and which components are involved in, procedures for testing the components in realistic conditions were planned using DoE and other techniques, containing information from:

- material characteristics (e.g. thermo-mechanical proprieties, stress factors)
- design procedures (e.g. by FEM optimization by Ansys, PAK or ModeFrontier)
- product specifications (e.g. mission profile, reliability end-on-line and in-use targets..)
- customer care and maintenance services (e. g. software for reliability)
- accelerated life test methodology (e.g. statistical models for interpretation, accelerated factors, etc.)

For example, the plastic body of the intake manifold (one of the most critical part) which participates to guarantee the resistance to thermal shocks (one of the most critical function) has to be tested under heavy conditions as:

- Temperature: -40°C till 130°C
- Atmospheric pressure: 3bar
- Relative humidity: 45-70%
- Test fluid: air at 700 kg/h while engine at 4500 rpm

to obtained the product qualification by experimental evaluation of reliability. As in a large number of other similar circumstances (Fragassa *et al.*, 2006), validation tests, accelerated or not, were supported and driven by a FEM structural analysis (Figure 8).

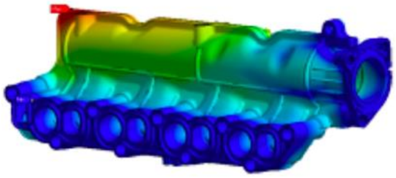

Figure 8. Simulation of thermal shock validation tests for the intake manifold body

4. Accelerated Life Test (ALT)

4.1 Generalities on ALT

In today's competitive marketplace, product design teams are under huge pressure to reduce product lead times. For example, in the automotive industry, product lead times, which often exceeded 48 months 10 years ago, are now below 24 months. At the same time, the level of reliability of modern products are so high that experimental tests using like-real conditions would be so long (it is not uncommon to see a durability test requiring thousands of cycles or hours of test time) and fruitless (it is not uncommon to see a large number of samples under testing to observe few or zero failures) that normal tests are usually not timely or economically feasible. Consequently, engineers must identify opportunities to shorten test times defining Accelerated Life Test (ALT) procedures also using Design of Experiment techniques (Giannuzzi *et al*., 2000). For instance, the use of experimental temperatures higher than the normal temperature in service is a common approach to reduce the test times. According to chemistry and physics, higher temperatures accelerate the kinetics of chemical reactions, resulting in an acceleration of physical and chemical phenomena like corrosion processes, oxidation, and other chemical breakdowns. Additionally, elevated temperatures lead to the material expansion and possible phase changes. The benefits of accelerated testing are well known:

- Better understanding of the effect of various stresses on product life
- Improved reliability by identification and elimination of design and process deficiencies (FRACAS)
- Shorter design and process validation which lead to an overall reduction in product lead times
- Reduced product development costs

At the same time, material properties and system responses might be affected by dissimilarities (e.g. coefficients of expansion) related to acceleration conditions even creating new failure modes or new evolutions of existing failure modes that the customer might have never experienced under normal usage conditions.

Most common procedures for accelerated life testing and following interpretation of results are:

1. Log-Log stress life
2. Overload-stress
3. Combined-stress percent-life
4. Deterioration monitoring
5. Step-stress

For a correct application of these methods, one single accelerated stress factor should be applied each time: all the others should be kept constant.

The failure modes, occurred during experimental testing, should be the same observed under use-stress conditions and all tests should be repeatable. In the particular case, e.g., of temperature like acceleration factor and composite material with characteristics deeply changing with the temperature, a good solution could be obtain using the combined-stress percent-life as accelerated reliability testing. This model analyses the results when one unit is tested to failure at an evaluated stress level and another unit is tested-first for a fraction of its life at the use-stress level, and after that at the high stress level used for the first unit-until this second unit fails. A linear approximation relates stress level and life time, from which the use-stress life is determined. This model can be applied with a minimum of 2 components for a quick reliability estimation.

4.2 Use of ALT in an integrated way

In the case of the Intake Manifold, a preliminary study, integrating several TQ instruments, has been implemented with the aim to pinpoint criticalities and, for each of them, to design the proper accelerated experiment. For instance, during the FMEA the intake valves mechanism (Figure 9) was identified as one of the most critical function (= high Risk Priority Number). The same FMEA also oriented the research toward its potential failure causes. A Finite Element structural analysis permitted to identify the plastic shaft as the weakest part (Figure 10), but also to verify constraints and loads. Specifically, it was evident the high risk related to unexpected flexural loads (e.g. related to inaccuracy in assembly) respect to torsional loads.

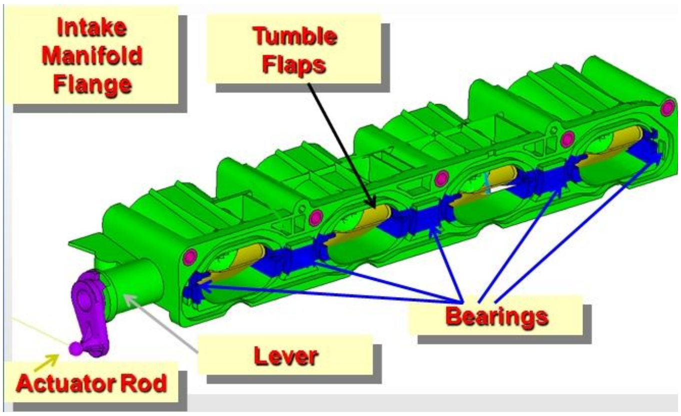

Figure 9. Intake manifold valves actuation mechanism

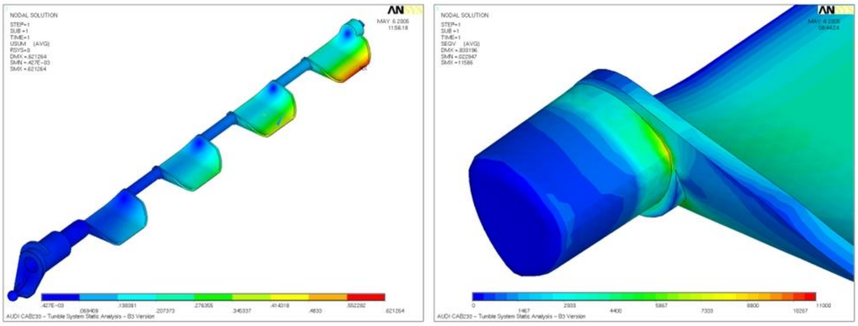

Figure 10. Stress/strain simulation for valves and shaft mechanism

A FTA estimated the impact of a potential failure both at the level of component (the intake manifold) or the system as a whole (the engine). All this information were used, by a Design of Experiment methodology, to *design* the proper ALT. A specific equipment was designed and manufactured with the aim at providing *pure* torsional loads (Figure 11).

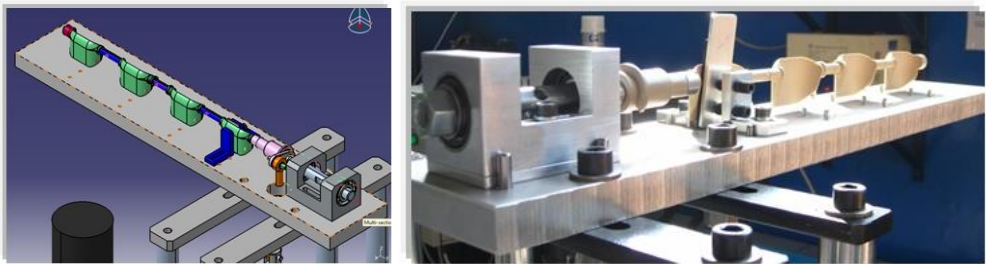

Figure 11. Design and realisation of equipment for ALT

Disconnecting flexural and torsional effects, it was possible to perform accelerated fatigue tests in a easy way, using a INSTRON servo-hydraulic testing machine (Figure 12). Experimental data were collected and used for a better estimation of reliability.

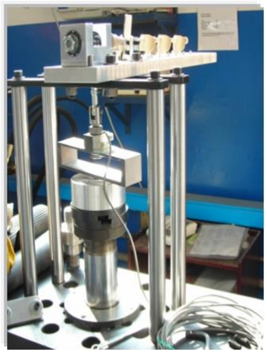

Figure 12. ALT performed by a standard testing machine

5. Conclusion

Due to the rapid evolution and the high criticality of the modern automotive market, even slight deviations in reliability targets or discontinuity in the production capability, can provoke very huge losses for a car company. Even minor inobservances in design specification or in manufacturing processes of the sub-components by suppliers can lead to severe effects to the final production inside the automotive factory. Quick responding methods and well-defined problem-solving strategies are necessary to overcome these barriers.

The aim of the article was to provide a large overview of practical examples in which theoretical and experimental methods were profitably used for reliability, safety or maintainability improving on the same automotive device in a modern approach of total quality for design and process validation. Specifically, on one side, Design of Experiments (DoE) can be used for planning the accelerated experiments; Analysis of Variance (ANOVA) for reducing the variability of measurements; failure models for interpreting the physic of phenomena of damage. On the other side, Failure Reporting, Analysis, Corrective Action System (FRACAS) and Failure Mode and Effect Analysis (FMEA) are irreplaceable to highlight on which criticalities to focus the experimental research, Fault Tree Analysis (FTA) and Reliability Analysis of in-service failure Data (RDA) to foresee the theoretical and authentic behaviour of reliability. Only strictly joining the Design for Experiments techniques (DOE, ANOVA, etc.) to the Design for Quality methodologies (FRACAS, FTA, FMEA, RDA) is possible to manage an integrated approach of Total Quality (TQ) and the reliability moves besides the current limits. Reliability improvements were focus on an largely spread family of air intake manifold, already installed or next to be installed in millions of specimens on different car brands. This system has to be progressively improved in reliability. Only joining theoretical knowledge, simulation analysis and experimental results, it is possible to obtain complete, fundamental information for further researches and manufacturing.

TQM tools, if properly utilized, can be extremely useful to interpret reliability of the product, to allow shorter testing procedures and a fast way for removing mistakes that are noticed in basic experimental diagnostic.

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