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QUALITY IMPROVEMENT IN THE DESIGN OF MECHANICAL SYSTEMS

M. Fargnoli and U. Pighini

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1. Introduction

The attention towards best achievable Quality in products development leads Manufacturers to look continuously for the ways and the means to reach this pursue.
A considerable effort in this direction may give satisfactory results only if the values of other two parameters are reduced at once. These parameters, to be considered together with Quality Level, are Time and Cost required for product's development.
Looking at all this by a historical point of view, we see that, as time went by, the consideration of Quality moved gradually from the end of a product's development process to its beginning, thus involving quickly and totally all its phases.
If therefore we desire to increase a product's Quality, there isn't any more useful tool than the one inducing to increase the Quality of its Design. This way is underlined the basical axiom that could be easily represented by the following sentence: "The higher Design Quality, the higher Product's Quality".
The study carried out is set in this sphere: it is an attempt to find the right trend to follow to pursue improvements in design activity throughout Methodical Design Tools. So it was possible to define exactly the way to cover, which, even in its complexity, leads to a very effective Procedure, to be followed by any designer without many difficulties.

2. Background

Usually, the term "Quality" is used as referred to very different and sometimes conflicting objectives. Sometimes a product is considered to have a better quality if it is ascertained as more durable, while on the other hand Quality is often misunderstood with the high or low level of performance obtainable from a Mechanical System; and in many other cases the fulfillment of aesthetical properties affects in a rather considerable manner the usual evaluation of a Mechanical System, leaving the objectives out of consideration.
The way of considering "Quality" went through a continuous evolution: from Quality as "fitness to use" (Juran), to Quality as "conformity with specifications" (Crosby), till the present definition of Quality as "customers satisfaction".

2.1 An Overview of Quality History

The definition of Quality is not a problem of today at all, but it was born when man created his first manufactured good and gave it a sort of evaluation such as to verify the issue of the work done; or using Juran: "Quality is a timeless concept, so the origins of the human approach to managing for quality are hidden in the mists of the ancient past."

Only the Industrial Revolution brought a real change of direction in this field, but nevertheless there was no real change or progress until the beginning of the XX century, when two important "milestones" were set. In fact, during the first 50s of the last Century the primary way of assuring quality to customers was inspection after production stages: products were checked to see if they were good enough to ship with the aim of reducing scraps and reworking activities, Figure 1.
After II World War, it was plane that the pursuance of Quality was not depending on a further control on the product, but it depended on the optimization of all the activities contributing to the manufacture of a product.
The evolution of Quality involved a significant mind-set transition from reacting to inspection events to utilizing process management tools and models in engineering and manufacturing stages: in 1961 the approach of Total Quality was first introduced by Feigenbaum in his book "Total Quality Control: Engineering and Management" (as "an effective system to integrate the efforts towards the development, the maintenance, and the improvement of Quality so that manufacturing and customer assistance give warranty of a full customer satisfaction with a minimum cost").
During those years in Japan (with the influence of USA experts, like Deming and Juran) originated the "Total Quality with Japanese style", as it was defined by Kaoru Ishikawa, or otherwise the "Company-Wide Quality Control" (CWQC).
On the trail of these brand new ways of thinking, Quality has been gradually extended to any producing activity and was pointed out the great liability of the Design activity on Quality: while on one hand this change of direction deepened in a significant way this influence, on the other hand it allowed to reach an effectiveness in results, that could be really difficult to pursue with the support of the procedures previously used.

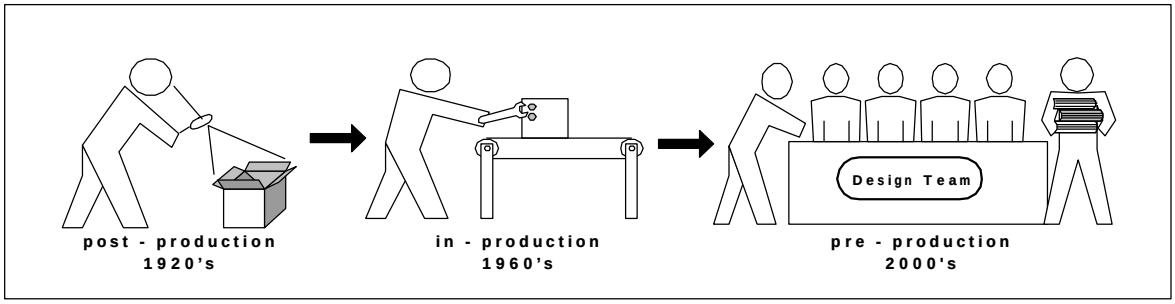

Figure 1. The Quality development

2.2 Methodology and Theoretical Basis

In parallel with the evolution of Quality, was implemented a great number of tools (standards, techniques, methods and strategies), which involves the whole product's life-cycle stages, to lay the proper foundation for good design and enable the process levels to work better (Smith; Suh; ISO 9000 standards).
The primary importance of design activities in improving quality level of products was detected by many Authors, which deeply studied such problem and proposed a set of strategies and tools in order to point out the deep relationship between Quality, Cost and Time.
In Engineering Design field, we can distinguish three main approaches oriented to Quality improvement (Hundall, Beitz):

- the Systematic Design Methods, developed in Europe;
- the Japanese methods and particularly Quality Function Deployment (QFD), Taguchi Methods and Fish-bone Diagram (FBD);
- the American approach, based on Value Analysis/Value Engineering methods.

In the ambit of each one of such theoretical ways to face the problems connected with quality improvement, were proposed a lot of Design Tools, characterized by different way to use, complexity, effectiveness and efficiency, and usually oriented to solve only specific problems.
Nevertheless, the evolution of market requirements in the last years has deeply transformed the designer way of thinking and operating: designing to success needs a more complex and global

approach, which obliges designer to consider a great number of parameters and constrains.
On the other hand, the average knowledge about such Design Tools is very low and only large Companies use a limited number of them, often in an incomplete way.

3. Methods

The wide development of new tools and methodologies of these last few years is an index of the great attention given to Design and of the acknowledgement of the important role performed within the burdens of products' Quality; on the other hand it is clear the need to organize the use of such tools in order to improve their choice and implementation.
The first step in this direction was a deep study on available methods and techniques, so to define for each of them its aim, way of use, moment of use, effectiveness and correlation with other Design Tools, in the right way.
Particularly, on the basis of a deep research started in 2000 (and partially sponsored by MIUR, Italian Ministry for Public Instruction and Research) which regarded all aspects of product development from the designer point of view, Quality ought to be considered as a product property, not like an elementary property, but like a "complex" one. If we make an attempt to give a numerical evaluation of it, we can write:

$$Q = f(P_1, P_2, P_3, \ldots, P_n)$$

Where P_i (i = 1,2, ...,n) is the generic elementary property (Reliability, Safety, etc…).
Usually all these properties are not of the same relevance to Quality: some of them ought to be considered as more important than others and the designer has to pay specific attention to them. So those properties, which seemed particularly important for its definition, were outlined.
They are as follows:

- Aesthetics
- Assembly
- Disassembly
- Environmental Compatibility
- Ergonomics
- Maintainability
- Performances
- Recycling
- Reliability
- Safety.

For each one of the over-mentioned properties were developed some techniques DFX, whose basis are set in a deep study of each single property itself, with the purpose to define useful Design Rules throughout a specific study.
The modules, where all the different Design Rules meet, are all together a very effective tool, to be used by the designer together with specific and well defined Tactic Tools (Design Methods).
This way, a set of "Design Tools" is at designer's disposal and he uses them "ad hoc", when it is required by the specific conditions.
Finally, with the aim to make faster and easier the design activities, all such Design Tools were implemented in the Design Strategy: for each of these modules were defined the proper moment of use and the proper sequence in order to reach results with the maximum effectiveness during each phase of the Design Process (the Methodical Design Process by the School of Rome), like a box containing useful information and tools for product's Quality improvement (Fargnoli & Pighini).
So it was possible to define exactly the way to follow, which, even in its complexity, leads to a very effective Procedure, to be used by any designer without great difficulties.

4. Results

4.1 The Procedure DFQ

The development of the Procedure "Design-For-Quality" (DFQ) comes out from the orderly and methodical combination of all the informations collected till now.
The Design tools considered include both Design techniques and Design Methods, Standards and statistical data should be considered as well, nevertheless the specific type of these supports depends directly on the particular design problem to be considered, especially for what concerns Standards.
So, not to belittle the generality and flexibility of the Procedure which, should be underlined, may be implemented on any Mechanical System's design, design tools are not explicitly integrated. A similar consideration should be done referring to methods and techniques not considered in the procedure: in fact we only considered the "Design Tools" that more directly should affect a Mechanical System's Quality during its Design, but any other Design Tool may be used considering the specific problem that should be solved; Figure 2 shows a possible example of the application of the Procedure DFQ.

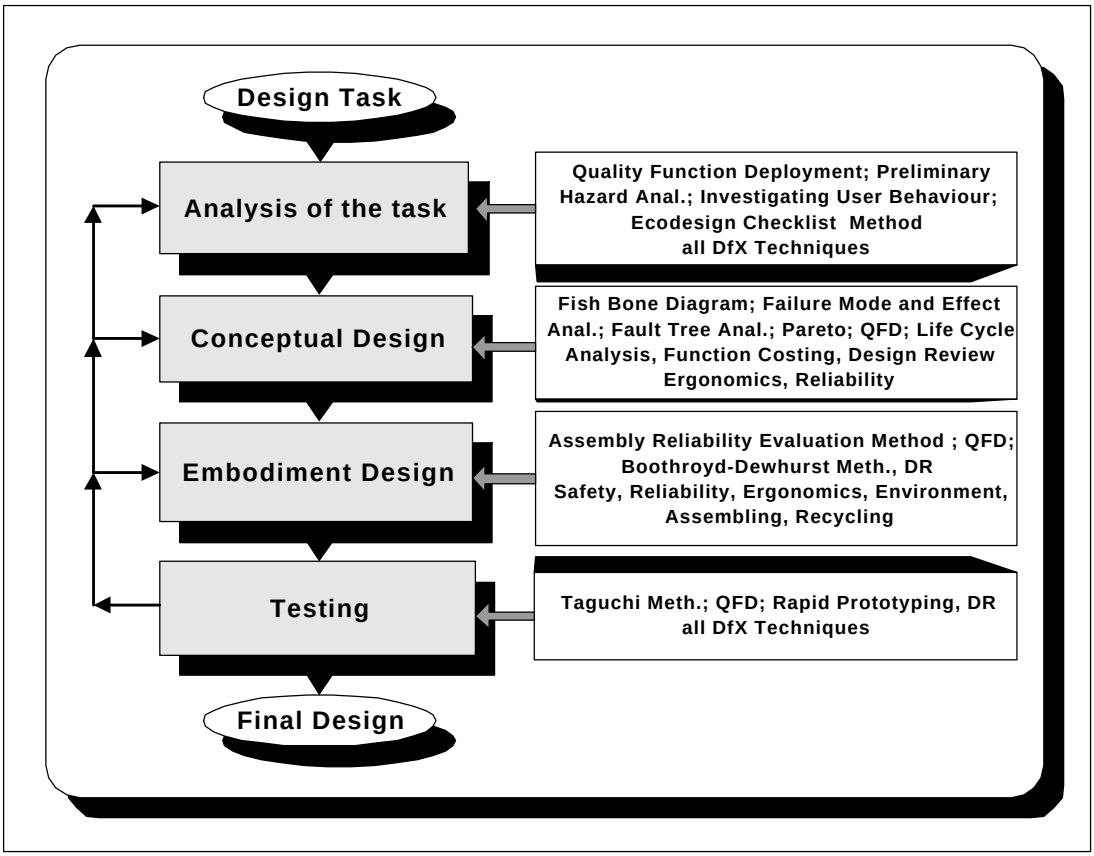

Figure 2. A possible example of application of the Procedure DFQ

4.2 ISO 9000, QS 9000 and Six Sigma

The implementation of the DFQ procedure is well integrated with the recent evolutions of Quality in Industry. In particular some wide areas may be pointed out where the use of some of the proposed Tools is already active, and where the use of the DFQ Procedure may be of great help:

- **ISO 9000**. Some design techniques and tools have always constituted a good help into Quality Systems implementation (FBD, Pareto, Design Review, etc.). In the last edition of the standards (ISO 9000:2000), dedicated to Quality Management Systems implementation, Design and Continuous Improvement have a key importance, referring explicitly to a series of Design Tools (ISO 9004), which not only could be used for Control, Check, Validation of

Design Activities, but also in other processes improvement by using FMEA, FTA, QFD, LCA, Design for Ergonomics, Design for Maintainability, etc.

- **QS 9000**. The "Quality System Requirements 9000", standards of the “Automotive” field, recently revised with the issuing of the Technical Specification ISO/TS 16949, originated from the necessity to uniform the existing national standards: AVSQ '94 (Italy), EAQF '94 (France), VDA 6 (Germany) and QS 9000 (USA); such standards forecast more restrictive requirements then the ISO 9000, and in particular it is given a greater specific weight to the design stages, promoting the use of numerous techniques and methods.
- **Six Sigma.** This methodology became famous for the excellent results achieved by Motorola Co towards the end of 80s. It has, as target, the pursuing of a performance level near to zero for each process inside the company by means of application of a series of techniques and methods, such as: FMEA, FTA, QFD, Pareto, FBD, etc. The effectiveness of Six Sigma and of Design For Six Sigma (DFSS) may certainly be improved by new methods introduction, e.g. AREM, TRIZ, VA/VE, and, most of all through their use into a systematical and methodical procedure. (Smith).
- **Customer Satisfaction & Quality Measurement.** The “Customer oriented” management requires the use of methods for the evaluation of his satisfaction and to identify the quality of the given products. By this point of view, the attention is directed to products analysis during Design and Development, throughout the definition of some indicators capable to give *a priori* an evaluation of product’s quality. For this purpose the use of Benchmarking, QFD, Taguchi Method etc., may be winning.

5. Case Study

The effectiveness of DFQ Procedure was tested on a project in cooperation with AMA s.p.a. (Agency for Environment of the City of Rome), regarding the redesign of a particular machine used to cut bushes (a tripper), which should be used for road cleaning. The project is only in the first stages, but were already achieved considerable results.
The specific conditions, in which this machine is used for, pointed out a series of particular problems, which were not been considered by the producer of that machine:

- the throwing of stones, sands, etc. all around the working area
- difficulty in transportation and preparing “set-up”
- difficulty of circulation in urban cycle (holes, side-walks, ridges, etc.)
- the user wearying in very short time.

Moreover we could point out the specific problems of such a machine, concerning:

- users safety
- maintainability
- reliability
- etc.

The implementation of the DFQ procedure in its earlier stages allowed to underline such problems and suggested the changes to perform: in particular, at the end of the 2nd phase of the Design Process a prototype was done, using as basis an existing Mechanical System, on which:

- a protection for the engine was added
- a protection against throwing of objects
- wheels with a greater diameter were used, with the aim to make easier surmounting road asperities.

In Figure 3 is showed the fist prototype of the tripper with the over-mentioned modifications.

6. Future Work

The results achieved could be considered very good: the next step will regard the improvement of Safety, Ergonomics and Reliability, by means of new control devices, lighter materials and protective barriers, easier to put on and steal off.

Figure 3. The fist prototype of the MS

7. Conclusions

Design has nowadays become a very complex task because it should take into account the whole life cicle of a product and take care of markets needs and expectations. The Design Procedure shown surely ought to be applied to the "Design for Quality" of any type of mechanical product. In fact, as it comes out from the structure of the Procedure, it allows a systematic development of Design, that makes difficult the occurrence of mistakes or the pursuance of not good solutions. In fact the wide and continuous use of various useful tools is a warranty for the final result of Design Activity, going straightly towards the best achievable optimization.

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References

Beitz W., "Quality through customer integration and Systematic Design", Proceedings of International Conference on Engineering Design, ICED '97, Tampere, 1997.

Fargnoli, M.; Pighini, U., "Integrating Design Methodology", 11 Symposium "Design for X", Schnaittach, 12-13 October 2000, Erlangen 2000.

Hosnedl, S. et al., "Increasing the level of TQM methods using Design Science", Proceedings of International Design Conference, DESIGN '98, Dubrovnik, 1998.

Huang, G.Q., "Design for X: Concurrent Engineering Imperatives", Chapman & Hall, London, 1996.

Hundal, M.S. "Design Methods: a synergistic view", Proceedings of International Conference on Engineering Design, ICED '97, Tampere, 1997.

ISO Standards: ISO 9000:2000; ISO 9001:2000; ISO 9004:2000.

Juran M., "Quality Control Handbook", McGraw-Hill, 1979.

Pighini U., "Design for Property, Design for Quality", ESA, Roma, 1991.

ReVelle, J. B., et al., "The QFD Handbook", John Wiley & Sons Inc., New York USA, 1998.

Smith, L: R, "Six Sigma and the Evolution of Quality in Product Development", Six Sigma Forum Magazine, Vol. 1, November 2001.

Dr. Ing. Mario Fargnoli
Chair of Machine Elements and Methodical Design
Dept. of Mechanical and Aeronautical Engineering, University of Rome "La Sapienza"
via Eudossiana, 18 – I – 00184, Rome - Italy
Tel.: 0039-06-44585236
Fax.: 0039-06-4881759
Email: m.fargnoli@dma.ing.uniroma1.it