

Application of DCOR-QFD model for improving the process performance and quality of the product

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Abstract

In this case study, DCOR - QFD model has been experimented as a product development process in the forging industry to assess the business process performance of the company, improving the heat treatment process and machining process. The present business process performance characteristics values were calculated using DCOR-1 model. The revised processes for improving the heat treatment process and machining process were identified. In this research, the performance of the integrated DCOR-QFD model was not evaluated in this research. The business process performance of the company using DCOR-1 model and the revised processes for improving the present processes were identified using QFD were calculated separately.

Keywords: DCOR; QFD; Forging; Heat Treatment; Machining.

1. Introduction

Product development is an important process in the manufacturing industries. As per the surveys reported among 1000 fortune US companies, one-third of the profits is generated from the newly introduced products [8]. Success full companies modify their existing products periodically or introduce innovative products in order to stay competitive in the market [16]. Product introduction must be at a faster rate, introduce the product with innovative features to satisfy the customers and the products must be cost-effective. For many companies, the product development is essential for the growth of the company, survival of the company and for configuring the company. Companies introduce flexibility in their PD process and add state of the art innovative features in their products.

PD processes must be capable of meeting the requirements of the customer and shorten the product development time in a cost-effective manner. In the year 2006, Supply chain council introduced the design chain operations reference model-1 (DCOR-1). In this research, the quality function deployment was integrated with DCOR-1 model and the PD process was performed by QFD. QFD uses the design approach, introduced by Yoji Akao in the year 1966. The structure of QFD is the network of quality, which improves the quality of the product and network of the process, which improves the PD process [12]. While integrating QFD with DCOR-1 model, the structural integrity of QFD has to be maintained.

2. Literature survey

Two well-proven models of QFD are 1) Akao's comprehensive QFD model and 2) American Supplier Institute's four-phase model of QFD [9]. In this study, ASI's four-phase model of QFD was used. The model consists of four matrixes connected serially. The

first matrix is the planning matrix, the second is design deployment matrix and the third is the manufacturing process planning matrix and the fourth matrix is the production planning matrix. The prioritized customer requirements were the input to the first planning matrix. The customer information was refined in each of these four matrixes and final result from the fourth matrix will be an actionable level of the customer requirements. In order to restrict the size of the matrix, only the important engineering characteristics were passed on to the next level of the matrix in each stage. The three important methodologies or procedures that formed the present day QFD are [19]

- 1) How to chart out quality assurance points to make sure that the quality is maintained throughout the process.
- 2) The flows from value engineering and quality deployment. Quality deployment means the process which converts customer demand into design quality of the finished goods. This final quality is achieved by deploying this design quality into component quality, individual part quality and finally to the process quality.
- 3) Quality chart and narrowly defined QFD. Narrowly defined QFD is the deployment of systematic operations to meet the process and product requirements. Quality chart which converts true customer requirements in terms of functions, which are the true quality characteristics.

Some of the benefits of using QFD process are, the complete customer requirements are deployed into product development processes, which can only be materialized through the QFD process [3]. By the use of cross-functional and multi-disciplined teams which are the enablers of QFD/FMEA product development process [7]. QFD uses series of matrixes; it improves the group thinking process and also able to cooperate different functional teams in the PD process [1]. Because of this series of matrixes, the information flow from customer to the final user is possible. QFD increases the process performance by reducing the product development time, reduces the cost and improves the customer satisfaction. QFD is effective in developing less complex products and

ineffective in developing radical product design and developing products from clean slate [1]. In the QFD process, the matrixes are serial in nature; one phase can be started only after the completion of the earlier phase [2]. QFD is a structured process, which does the quality planning in the concurrent engineering [9], [15].

By applying DCOR model, the companies participating in the product development can exchange information among the companies and also be able to apply design chain management practices among interested parties. DCOR model improves the business process of the product development processes, increase customer satisfaction and finally improved product demand. The DCOR has 3 levels of process details and one implementation level [10]. At level 1, the model contains 5 management practices plan (P), Research (R), Design (D) Integrate (I) and Amend (A). At this level, the scope and content of the DCOR model are defined and the performance targets are decided. At level 2, Configuration level, DCOR is a configurable process reference model. Here as per the requirements of the company's strategy, the business process can be configured to achieve the required result. DCOR divides each management process into several process categories. The DCOR process categories are constructed around three environments (1) Product refresh (2) New product and (3) New technology [18]. In the DCOR model Research, design and integrate process has the common internal structure. At level 3, each of the process categories is divided into a set of standard process elements. Process elements have inputs, outputs, metrics and best practices. Here companies can begin to configure their business process to make the desired outputs. DCOR is a business process reference model; it integrates the principles of business process re-engineering, benchmarking and process measurement into a cross-functional framework.

Performance attributes of the DCOR-1 model.

- 1) Perfect product design
- 2) Design chain cycle time
- 3) Product design change cycle time
- 4) Total design change cost
- 5) Design chain asset value

DCOR-1 metrics

- 1) Perfect Product Design = $\frac{\text{Total Perfect designs} \times 100}{\text{Total designs}}$
- 2) Design change cycle time = $\frac{\text{Sum of actual cycle time for all completed designs}}{\text{Total number of completed designs}}$
- 3) Product design chain change cycle time = $\frac{\text{Sum of amended cycle time}}{\text{Total number of events}}$
- 4) Total design chain cost = $\frac{\text{Total design chain cost}}{\text{Number of products designed}}$
- 5) Return on design chain fixed assets = $\frac{\text{Design chain revenue} - \text{COGS} - \text{R\&D}}{\text{Design chain asset value}}$
- 6) Return to design chain working capital = $\frac{\text{Design chain revenue} - \text{COGS} - \text{R\&D}}{\text{Design chain working capital}}$

The performance attributes are the characteristics of DCOR model; it can be examined and assessed with other design chains with competing strategy. At level 4, the exact DCOR management practices can be applied at this level to attain the competitive advantage.

3. Methodology

The QFD is a communication tool; it converts user demands into substitute design quality of the finished good and systematically deploys this user requirement into component quality, individual

part quality and process elements and their relationships. The first matrix is the planning matrix or house of quality matrix. In the quality matrix, the voice of the customer will be converted into company measures. In the second matrix, design deployment matrix, the company measures are converted into part characteristics and in third matrix manufacturing process planning, were the part characteristics are converted into key process operations and finally the fourth matrix, the production planning was key process operations are converted into production requirements.

In order to stay competitive in the dynamic business environment, the PD companies which are geographically displaced, exercising complex product development process in a network of digitally connected product development process is possible only by integrating these PD companies across the value chain [20]. This collaboration is possible only through the design chain collaboration framework. It is a virtual framework; managers can cooperate or collaborate with different enterprises in the design chain for PD process. The design companies can outsource less skilled activities and also possible to make collaboration with SME's. Internet and Web-based technologies are increasingly important in the PD process [4]. It captures, visualizes and communicates electronically among multi-disciplinary teams when they are geographically displaced. It can link resources, equipment, expertise, and data sharing between companies. Using Web-based tools; it is possible to involve customers in the PD process, for collecting data and for the communication among the design chain members. Web-based and agent-based approaches are identified as important enabling technologies for the implementation of distributed collaborative design chain [13].

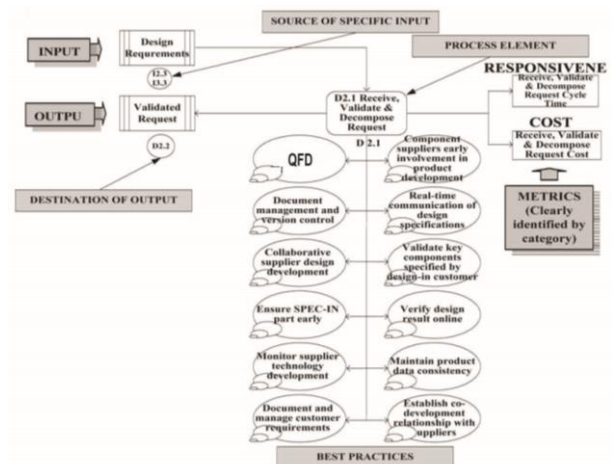


Fig. 1: DCOR-QFD model.

In order to strengthen the value chain, different enterprises with core capabilities within their respective field must be united across design chain to improve the product development process. The DCOR is a virtual framework, which streamlines different companies and different teams in the design process. The design processes are inherently resource dependent and content dependent. The design chain framework must be capable of improving growth, improve process innovation and increase information efficiency. The DCOR model works on process re-engineering principle, the process can be designed by IT and process managers. The web-based tools and internet are the infrastructure for the DCOR model. These tools can integrate resources, equipment, knowledge, and expertise. DCOR model can improve the time-based competition. In this DCOR-QFD model, the main product development process is ASI's four-phased QFD model. QFD inherently improves the quality of the product in a systematic manner. By the integration of DCOR and QFD, the new model improves the quality of the product, reduces the product development time and cost. The process performance can be measured using DCOR matrices and performance characteristics can be improved by using the appropriate best practices provided by the DCOR model. To improve PD process, it is possible to apply DCOR spe-

cific management practices in the implementation level among the design chain partners. DCOR is a continuous improvement process model. With this DCOR-QFD model, the customers and suppliers can cooperate in the PD process to improve the quality of the product and to improve the process performance. Since the time required for implementing the proposed DCOR-QFD model is 5 to 6 years, the effectiveness of the model cannot be assessed in this research. In order to find the effectiveness of this model, a questionnaire was prepared and distributed to high ranking managers of five design and manufacturing company executives and the feedback were collected.

4. Case study

The case company is an AS 9100C certified public sector company specialized in manufacturing forgings of Titanium, Super Alloys, Alloy Steels and Aluminum. The annual capacity of the company is 7500 metric tons and the number of employees is 500 numbers. The company makes forgings for aerospace industries, defense equipment, commercial vehicle components and components for Indian Railways. The important departments in the case company are Forging die design and development, Forge shop, Heat treatment unit and Machining unit. The case company is a regular supplier of forged components for Indian Railways. At present the case company received a contract to supply gear blanks in the ready to hob condition to Indian Railways. The first lot was supplied to Indian Railways and was rejected due to two complaints. 1) 12% of the gear blank supplied was not meeting the dimensional requirements. The dimensional requirements include not meeting blue matching 75% of the central tapered bore and did not meet the concentricity of the workpiece within 25 microns. 2) 89% of the first lot was rejected due to variation in hardness within the allowable limit. The permitted hardness variation was between 332 BHN and 364 BHN. The objective of the study is to revise the heat treatment process and machining process to meet the quality requirements of Indian Railways. In this study DCOR-QFD model was used to rectify the non-conformity of the gear blank and to improve the business process improvement of design chain. In this process, the QFD process was used for rectifying and improving the present processes. The ASI's four metrics model of QFD will be used in this model and QFD is a well-established process to improve the quality of the product. At present the case company was outsourcing both heat treatment and machining processes. Design chain operations reference model integrates design chain partners in the product development process in a seamless manner. The design chain partners include material suppliers, component suppliers, customers and case company design engineers. The value of the design chain means the core capabilities of the individual companies cooperating in the design process. The performance of the DC can be measured using performance attributes of DC. The process manager can decide appropriate process design. By the integration of QFD and DCOR model; it is possible to identify new heat treatment process, machining process and the present PD process can be measured and improved.

The important manufacturing processes in the camshaft gear blank are Forging die design, Forging processes design, Heat treatment processes design and Machining processes design. The process starts with the verification of incoming raw material AISI – A86B45VD steel with mill certificate. The steel contains a minimum of 0.005% Boron for better harden ability. The steel is in the form of billets, 240 round cornered shapes and is bands awed to 180 kg. The physical surface verification of the material will be done initially, which includes the identification of internal defects, blow holes and cracks. The case company does the chemical analysis of the steel; also verifies the grain size and the required grain size is 6-8 ASTM. After initial raw material inspection, the plant supervisors check whether the process is going as per the revised process chart.

In the upset forging process the Billet will be heated in open type gas fired furnace, its maximum temperature is restricted to 1145⁰C and it is done by using platinum-rhodium thermocouple fixed in the furnace. The soaking period for the workpiece will be 60 minutes, flat dies are used for forging operation and 6-ton hammers will be used. After upset forging, the diameter of the workpiece will be 640mm and thickness 75 ± 5 mm. In the next final forging operation, the workpiece is again heated in the same furnace where the maximum temperature will be restricted to 1145⁰C and soaking period will be 60 minutes. A 10-ton hammer will be used for this operation and is done in a closed die forging process. The dies were pre-heated before the final forging operation. It is heated to 250⁰C and was lubricated using furnace oil. In the final forging operation, center the raw gear blank in the die impression and finish with heavy blows and descale before the finishing blows. In the pre-machining operation, the operations are trimming, removing flash and slug. Then machine 2mm excess material from the raw gear blank. In the normalizing process, the material is heated to 870⁰C, the rate of heating is 1 hour per inch, the soaking period is 3 hours and cooling will be done in air. Normalizing is carried out in an electric furnace of temperature uniformity ± 10⁰C. Normalizing is a critical heat treatment process; otherwise, lots of dimensional variation, distortion or microstructure variation happens during the machining process, which ultimately creates non-uniformity of hardness in the raw gear blank. Hardening process is done in the high heat gas carburized sealed quench furnace. After the gear blank is heated to 870⁰C and then quenched in oil, quench delay must be less than 15 seconds to 18 seconds. The oil bath temperature must be maintained at 80⁰C, oil bath is connected to the heat exchanger with variable speed agitator to maintain the temperature of the oil. The workpiece is held at this temperature for one hour. During hardening process, the thinner sections of the gear blank must be properly masked to avoid overheating. In the tempering process, the raw gear blank is heated to 520⁰C in the electric furnace and soaking time is 8 hours. The low-temperature furnace is used for this purpose. The workpiece is then cooled in the furnace; the cooling rate is 2 hours per inch in order to produce the uniform hardness. After the tempering process, if the hardness is less than 364BHN, the raw gear blank will again send for hardening and subsequently the tempering process. If the hardness is 364BHN, the gear blank will be sent for final machining.

In the final machining operations, the machine tool used will be vertical or horizontal CNC turning center. The machine must be capable of producing components of 5th quality (5H). While machining, care must be taken to avoid stresses developed in the thin sections of the gear blank. The raw gear blank is held at the outer diameter by using the chuck and machine one side of the gear blank. Then do the machining, the order of machining operations are facing, drilling, turning, boring, step turning, and taper turning. After the taper turning operations, check the tapered hole using the blue matching gauge. If the tapered hole is not meeting the blue matching 75%, the bore grinding operation has to be done. After finishing the taper turning, the taper turned portion of the gear blank is fixed on the mandrel. Then mandrel with gear blank is fixed on the turning center for further machining. Then correct the outer diameter of the gear blank. By changing the position of the mandrel, the other side of the gear blank can be machined. The material to be removed from the workpiece is approximately 1.6mm. The depth of cut for the final operation is 0.4 mm, the speed of the workpiece will be 400 meters per minute and cutting tool used is coated carbide tool. After the whole operations, the final testing of the ready to hob gear blank is; microstructure analysis which includes microstructure evaluation using optical microscope, dimensional check, hardness check, magnetic particle test and grain flow line check.

	Heated to 850°C high heat electric furnaces	Quenched to 150°C, 1 hour holding time	Heated to 520°C in low temperature furnace. Soaking time 8 hours
Hardening	9	9	1
Tempering	1	1	9
	10	10	10
	-	-	-

Fig. 4: Manufacturing Process Planning Matrix.

	Hardening and tempering	Hold the work in check. Machining. Blue matching.	Fix work piece mandrels, machine outer dia and sides.
If hardness is less than 364 BHN re harden. If the hardness is 364 BHN do the machining.	9		
Final machining process		9	9
	9	9	9
Maximum hardness 364 BHN.			
Confirm blue matching 75%			
Confirm concentricity with in 25 micrometers			

Fig. 5: Production Planning Matrix.

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