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Six Sigma based approach to optimize radial forging operation variables

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ABSTRACT

The present competitive market is focusing industrial efforts on producing high-quality products with the lowest possible cost. To help accomplish this objective, various quality improvement philosophies have been put forward in recent years and of these Six Sigma has emerged as perhaps the most viable and efficient technique for process quality improvement. The work in this paper focuses on implementing the DMAIC (Define, Measurement, Analyze, Improve, and Control) based Six Sigma approach in order to optimize the radial forging operation variables. In this research, the authors have kept their prime focus on minimizing the residual stress developed in components manufactured by the radial forging process. Analysis of various critical process parameters and the interaction among them was carried out with the help of Taguchi's method of experimental design. To optimize the results obtained and to make the analysis more precise and cost effective, response surface methodology (RSM) was also incorporated. The optimized parameters obtained using Taguchi method and RSM were then tested in an industrial case study and a trade-off made to finalize the recommended process parameters used in manufacture.

1. Introduction

Radial forging is a unique process used for the precision forging of round and tubular components, with or without an internal profile. Since its development, this operation has found extensive use in both hot and cold forging operations. However it is sometimes confused in the literature with rotary forging (Hojas, 1988). Over the years, it has been continually improved and aimed towards automation, and the latest trend is the CNC integrated radial forging machine (Rauschnabel and Schmidt, 1992). In addition, this process possesses the capability for the virtually chip less manufacture of rods and tubes to provide a precision-finished product with an excess of 95% material utilization (Lahoti et al., 1977). Other common applications include the manufacturing of stepped, solid and hollow shafts; including axles for locomotives; preforms for turbine shafts, necks and bottoms of steel bottles, forged tubes for underwater drilling equipment; bars with round, square or rectangular cross-section and forged tubes from 15–1200 mm in diameter and 25–100 mm in wall thickness, etc. Fig. 1 illustrates some of the components manufactured by the radial forging process.

Components produced by radial forging typically have good mechanical and metallurgical properties and the process is generally preferred for the manufacture of high-value added products. This process facilitates the manufacture of hollow products from solid blanks without piercing (Hojas, 1988). The foremost application of this process is the manufacturing of

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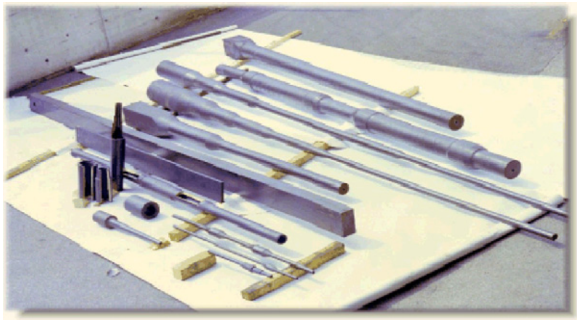

Fig. 1 – Forge components produced by radial forging.

high-pressure tubes for deep-sea oil and gas pipelines. Some of the economical benefits are:

- material savings of up to 30–50% are made possible in the manufacture of hollow products in comparison to products using technology involving drilling;
- lower effort is needed in the manufacturing of hollow products;
- reduction in load required by two to four times;
- forgings irrespective of length, size, and material are easily manufactured.

Since radial forging operations have certain specific advantages as compared to other alternatives, there is a need for process improvement. The design of the process is still typically based on the trial and error method, which is very expensive and time consuming. In today's competitive environment, this is extremely undesirable due to the requirement of shorter production runs and lead times. Therefore, it is important in practice to identify the process parameters present in a radial forging operation and to optimize them. Lahoti and Altan (1976) have contributed significantly by mathematically modelling the radial forging process. They implemented a slab method of analysis to develop a general model of the hot and cold radial forging of rods and tubes. Domblesky et al. (1995) used finite element based analysis to optimize the radial forging operation. Liou and Jang (1997) advocate a robust design methodology to optimize forging process parameters to give optimum stress distributions in products through FEM analysis. The above researchers have contributed significantly but in general they have not validated their work on the shop floor. In this research, we have addressed the problem from the implementation point of view. In recent years the Six Sigma philosophy has become a management philosophy and has helped in saving billions of dollars while improving customer satisfaction ratings and stock prices (Pande et al., 2000). This paper focuses on the implementation of the Six Sigma philosophy in order to optimize the variables of the radial forging process.

As a systematic framework for quality improvement and gaining business excellence, the Six Sigma philosophy has become the paradigm of the industrial world in recent years. Some of the proven benefits of the Six Sigma system are productivity improvement, customer satisfaction, defect reduction, cycle time reduction, and culture change, etc (Antony et al., 2005). From the view of statistics, this concept can be defined as a goal set for limiting the process variability within $\pm 6\sigma$ (i.e., total spread of 12σ) which leads to 3.4 defects per million opportunities (DPMO) for any process (Sigma or σ = standard deviation on the normal distribution). In order to meet with the lowest possible number of defects, the traditional three sigma limits are completely inadequate (Breyfogle et al., 2001). Six Sigma is a proven tool set for driving and achieving changes within a company. Moreover, it is a continuous improvement process, focusing on the customer requirements, process alignment, and analytical rigor. In order to accomplish the Six Sigma objectives, one of the most practiced methodologies is the DMAIC (Define, Measure Analyze, Improve and Control) approach (Koning and Mast, 2004). Systematic and disciplined implementation of DMAIC ensures that the causes of defects are found and eliminated by focusing on process outcomes that are of critical importance to customers. Table 1 delineates the generic flow of the DMAIC approach.

Table 1 – Generic flow of DMAIC approach in Six Sigma

Phase	Steps
Define	Identify and map relevant processes Identify targeted stakeholder Determine and prioritize customer needs and requirements Make a business case for the project
Measure	Select one or more critical to quality (CTQ) functions Determine operational definitions Validate measurement system Assess the current process capability Define objectives
Analyze	Identify potential influence factors Select the vital few influence factors
Improve	Quantify relationship between control factors and CTQs Design actions to modify the process or settings of influence factors in such a way that the CTQs are optimized Conduct pilot test of improvement actions
Control	Determine the new process capability Implement control plans

In this work, the prime focus is on minimizing the residual stress developed in components manufactured by the radial forging process. Thus, we have implemented DMAIC (Define, Measurement, Analyze, Improve, and Control) based Six Sigma approach to optimize the radial forging process variables and have made the process more robust to quality variations. Analysis of various critical process parameters and the interactions among them is carried out with the help of Taguchi's method of experimental design. Further, to improve the results obtained and make the analysis more precise and cost effective, response surface methodology (RSM) is also incorporated. Eventually, the optimized parameters obtained using Taguchi method and RSM are tested in a shop floor case study and a trade-off is made to finalize the recommended process parameters.