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Parameter design optimisation of computerised numerical control turning tool steels for high dimensional precision and accuracy

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Abstract

Dimensional precision and accuracy are often the most important quality characteristics demanded in the turning process. In this paper, a set of optimal turning parameters for producing high dimensional precision and accuracy in the computerised numerical control turning process was developed. Taguchi dynamic approach coupled with a proposed ideal function model, was applied to optimise eight control factors for common tool steels SKD-11 and SKD-61. The control factors were coolant, cutting speed, feed, depth of cut, coating type, chipbreaker geometry, nose radius and shape of the insert, which were designed in a L18 orthogonal array and carried out in the experiments.

The results showed that the factors associated with the cutting tool and feed had the most significant effects on the dimensional variation of the test piece. Once the eight factors were optimised, the dimensional variation of the product was reduced by 45.61% of the initial conditions and the dimensional accuracy of the product could be adjusted to a more ideal final value. Further, the average surface roughness of the optimised product was found to be better than most of the L18 experimental results and from the initial machining conditions. This indicated that the combined optimised process factors not only produced optimised dimensional precision and accuracy, it also resulted in improved surface roughness.

Keywords: Taguchi methods; Turning; Tool steel; Optimisation

1. Introduction

Turning is the one of the most widely employed machining processes for producing cylindrical and conical mechanical components. Traditionally, the machining parameters are selected either based on the experience of the operator and/or by referring to operation manuals provided by machine tool manufacturers, both of which are often effective only when targeting a single product quality. In view of the wide varieties of workpiece material currently available and the increasing demand of machining precision, accuracy and speed, the competitiveness of the machining industry can only be enhanced if there were a set of reference for designing a robust machining process that is suitable for a wide range of products.

One of the most commonly used methods for optimising the turning process is the Taguchi static approach with the surface roughness most commonly selected as the target quality characteristic to investigate the effect of various process parameters on the product. In practise, however, each material would be influenced by different machining parameters. It was reported that when turning S45C, SKD-61, 9SMnPb28k (DIN) and

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SUS303, the most important factors affecting the surface roughness of the product were feed, the insert nose radius, and the cutting speed [1–4]. Nain et al. [5] machined S45C steel with P-10 tungsten carbide tool to design the machining parameters for optimising multiple quality characteristics using the Taguchi static approach. Different weightings were used to define the function of the quality lost and the quality characteristics studied were cutting tool life, cutting force and surface roughness of test piece.

As tool wear has significant influence on the dimensional accuracy of products, therefore to improve wear, cavity and oxidation during machining, tools with multicoating layers are now commonly used in researches on turning materials with high hardness values. Jindal et al. [6] reported that the TiAlN coating layer had high thermal and oxidation resistance at high temperature applications. As such, it gave improved cutting efficiency as well as better resistance of the tool to wear than TiN and TiCN coatings during high-speed machining. Tsao [7] investigated the use of different materials as coating layers on cutting tools for turning the SUS304 steel and concluded that the cutting force was smallest for the coating of TiN/TiCN/TiN/TiCN/TiN and therefore provided the longest tool life for high speed machining.

Coolant prevents over-heating of the insert as well as the workpiece during turning and therefore brings about the advantages of low surface roughness of products, longer tool life and the ease of chip disposal and so on [8]. Many researches have been carried out on coolants, such as that by Avila and Abrao [9], who showed that when turning AISI4340 steel, tool life was prolonged when using emulsions that did not contain any mineral oil as coolants. In contrast, Diniz and Micaroni [10] reported that dry cutting AISI 1045 steel under low cutting speed, high feed and high nose radius resulted in a much improved surface roughness within a shorter machining time and energy usage. In addition, tool life was also enhanced. In recent years, the increasing awareness of environmental conservation resulted in increase publications on the advantages of green machining. Varadaraja et al. [11] investigated hard turning with minimal cutting fluid application (HTMF), which was revealed to improve the cutting force, tool life, surface roughness, cutting ratio, cutting temperature, chip production, and the contact length of the cutting edge etc., compared to traditional wet cutting.

The main demand in product quality of the mould and die manufacturing industry is often the geometrical precision and accuracy, in particular of the dimension. In the traditional methods of optimising machining processes, the key optimisation objective in assessing product quality is often the surface roughness and rarely the dimensional aspects. To extend the traditional optimisation method, this paper seeks to use the Taguchi dynamic approach in the design of experiments to develop a robust machining technique that is optimised in terms of the dimensional precision and accuracy, and is suitable for a range of steel materials. It is anticipated that this developed technique would increase the competitiveness of mould and die manufacturers by providing them with flexibility and effective response to the ever-changing demands of customers.

2. Taguchi methods

2.1. Engineering system with dynamic characteristic

Engineering system is a man-made system specifically designed for achieving a specific function. As shown in Fig. 1, a typical engineering system consists of four components, namely, input signal, control factors, noise factors and output response. An operator uses the input signal to inform the system of the required output response while the control factors, as the name implies, are the technical means designed to control the operation of the engineering system. Noise factors are not easily controlled or require huge cost to control. Theoretically, the output of any engineering system that possesses dynamic characteristics can be controlled by the input signal. In practice, however, the output re-

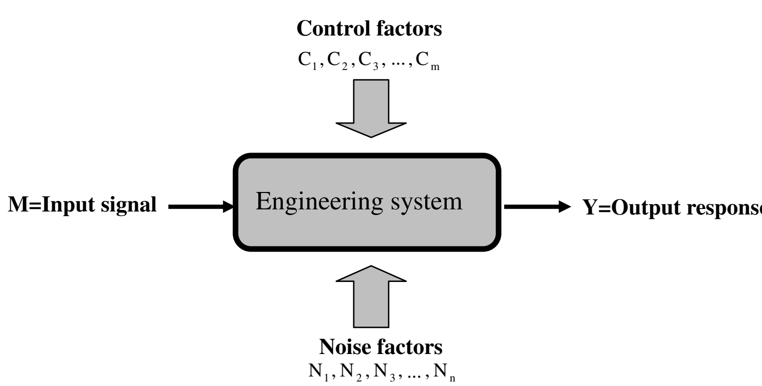

Fig. 1. The schematic of an engineering system.