11 Geometrical Adaptive Control of Manufacturing Systems

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11.1 Introduction

In the manufacture of discrete products in the mechanical, electrical and other industries there are three major objectives (1) good performance and reliability of the product; (2) competitive price related to comparable products on the market; and (3) high-quality products.

We shall deal in this chapter with the problems of how to achieve and maintain the quality of mechanical parts during production. Particular attention will be paid to automatic control of the geometrical parameters of parts produced in flexible manufacturing systems (FMS) or cells (FMC).

The quality of the geometrical parameters of parts is basically related to the following features: dimensional deviations, shape deviations and surface roughness. Information on these geometrical parameters is essential, and it is usually specified by the designer. The selection of allowable tolerances is closely related to the functional requirements of the product.

The quality specification must be carried out under conditions where fabrication of the parts may take place on various machine tools, as a function of the production time. There are many uncontrollable disturbances affecting the stability of the geometrical quality of parts [1]. These may have their origin in the dynamics of the machine tools and/or the manufacturing process itself or in the surface interface dynamics.

Our discussion will focus, therefore, on the conceptual development of the geometrical quality model of the part, which will result in a definition of dimensional accuracy and its transfer function (DATF). The stability of the geometrical quality is a time-dependent function, describing the state of geometrical accuracy of the parts manufactured as a function of time $t$.

In order to maintain the stability of the geometrical quality, it is necessary to develop a geometrical adaptive control (GAC), enabling the machining system to accomplish the objectives $\{Z^*\}$ related to the geometrical quality of the parts, as specified by the designer.

There are three areas that the designer of the GAC systems has to consider. Firstly, the means and methods of measuring geometrical deviations from the theoretical parameters. Secondly, the compensation systems enabling, for example, the change of relative position between the tool and the surface generated in order to maintain the tolerances, or change of the feedrate, cutting speed or some other
machining parameter contributing to the stability of the quality parameters of the part.

11.2 Quality of Machined Parts

The quality of a mechanical part is a complex characteristic related to its geometrical and material properties.

The designer specifies the quality of the mechanical components in relation to their functional performance required during the exploitation of a product, of which a particular component is a part. In addition, the useful life of the product depends strongly on the quality of its parts.

These specifications represent the reference values, expressing the objectives \( \{Z^*\} \), set by the designer, which have to be accomplished during fabrication of the parts.

Because of the various influences that affect both the material and its geometrical properties during the manufacturing process, the actual geometrical and physical values characterizing the quality of the parts may not be realized within the acceptable limits. Therefore there is a need for on-line quality identification and consequently adaptive control.

There are two sets of potential problems in developing on-line quality control during automated production:

1. The control of those material properties affected by the conditions under which the manufacturing process is implemented; and
2. The control of the geometrical parameters of the parts, in relation to the length and shape tolerances, the surface roughness, deviations from perpendicularity, parallelism etc.

We will now briefly discuss both of these areas of quality control.

11.2.1 Quality of Material Properties

The material of a blank represents an input into a manufacturing process in which a part is generated to within the designer specifications. Physical and chemical properties affect to a great extent not only the functional behaviour of the mechanical part under load, but also its fabrication by various manufacturing processes. There are two considerations to be taken into account:

1. The material properties affect the tool wear, which is one of the major parameters in optimizing the machining conditions. On the other hand to a great extent the tool wear influences the geometrical quality of the parts.
2. The forces and the temperatures at the machining interface cause structural damage to the surface of the part, as Fig 11.1 indicates.

Material properties can be changed during fabrication only in certain cases (e.g. heat treatment, plastic deformation of the surface, preliminary treatment before painting etc.). For this reason these properties cannot be the object of control in machining. However, it is necessary to establish effective quality control of the incoming materials from suppliers, in order to establish whether their properties are within the required specifications, and to minimize the uncontrollable effects on the