A Short Review On Measurement Methods In Machining Of Aerospace Materials

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***Abstract*— In-process measurements are becoming more and more popular among businesses as a result of the numerous benefits they provide, including reduced production costs, improved product quality, and real-time analysis of both production and product quality of aerospace materials. It is anticipated that the method of measuring manufactured components known as "in-process measurement" will become the standard practice in the not too distant future. After a description of the in-process measurement methods with the developed examples, an explanation of the usage of machine tools as a measurement device will be provided in this paper, along with the needs, issues, and challenges, and recent research work.**

Keywords*— *Measurement methods, machining, aerospace materials

I. INTRODUCTION

Technological developments have facilitated the manufacture of advanced engineering materials used in the aviation industry, improving their mechanical properties and expanding their application areas [1], [2]. In particular, the new generation composite materials developed by using machining methods by reducing the material on the part and additive manufacturing methods obtained by adding layers on the material have become used in all vehicle structures, especially the wing and body structures of aircraft used in the aviation industry. Table 1 shows the aircraft material composition accumulated in modern civil aircrafts by weight in percentage [3].

Table 1. The aircraft material composition accumulated in modern civil aircrafts [3]

	Airbus A350 XWB	Bombardier CS300	Boeing 787
Composites	52	46	50
Aluminum	20	24	20
Titanium	14	8	15
Steel	7	1	10
Others	7	21	5

During manufacturing, intermittent checks and measurements are often made before reaching the final product. These measurements are called in-process measurement and control (in-process measurement and control) if the part is connected to the machine, before it is taken from the production bench, and if the final machining process can be modified according to the measurement result [4]. The simplest example of measurement during the process can be considered as the operation of the operator who processes a part on a conventional lathe, and adjusts the last pass according to the measurement and measurement result taken while the part is connected to the lathe with a micrometer or caliper, without making the final pass [5]. This is done in the automation environment by measuring the part with more sensitive measuring devices for continuously working CNC machine tools [6] and giving feedback to the machine tool control unit so that it can rearrange the cutting parameters [7], [8]. In-process measurement is a method applied especially for the efficient manufacture of costly parts (expensive material or very large size) [9]. Many different measurement methods have been developed that can be used during the procedure [10]. These methods may vary according to the geometry, size, production environment and speed of the part to be measured [11]. It is possible to measure the part independently, as well as to control the factors affecting the production of the part or to make the necessary corrections with this process [12]. It is also possible to measure parts by using the axes of the machine tool, as well as measuring in a three-dimensional measuring device [13]. However, since the machine errors during machining will also occur during the measurement, the measurement result is significantly affected by the performance of the machine [14]. The use of compensating systems, which handle these errors separately and enable the measurement of complex and large parts, has come to the fore in recent years. Because measurement during the process overcomes the problems that reduce efficiency, increase costs and weaken precision production in the manufacturing environment [15]. In this paper, after an overview of the measurement methods during the manufacturing process, information will be given about the use of machine tools as measuring devices and sample applications. By informing about the current problems

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and the latest high-level scientific studies to solve these problems, important information will be given about the measurement during the process, which is expected to be the future measurement method for manufacturing.

2. EVOLUTION OF MEASUREMENT IN MANUFACTURING

The control of whether the manufactured parts are within the desired tolerances is a part of the production and is made by making use of metrology applications. Measurements for manufacturing have undergone a certain evolution, depending on the state of the work, its sensitivity, its cost, and new demands [16], [17]. It is possible to summarize this evolution as follows:

2.1. Open loop measurement control

After the production of the product is completed, the product is taken from the production bench and measured with measuring equipment. Generally, products that are out of tolerance are separated and sent to scrap. If the cost of the material used for the product is high or the manufactured products are large, this issue arises as a problem and causes a serious increase in the cost. Figure 1 shows an open loop measurement control in machining process [16].

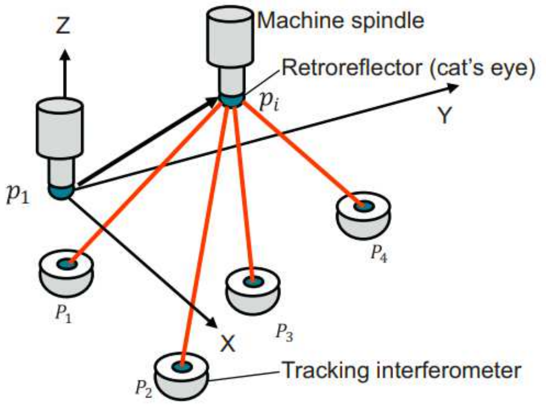

Figure 1. Open loop measurement control in machining process [16]

2.2. Closed loop measurement control

When measures are increased for low cost and precision production, measurements of products are made between production lines. According to the measurement results, some corrections are made by intervening in the production process. This process is applied especially in production lines using three-dimensional measuring devices. Corrections are made during the production stages by using the detected errors. Figure 2 demonstrates a close loop measurement control in machining process [17].

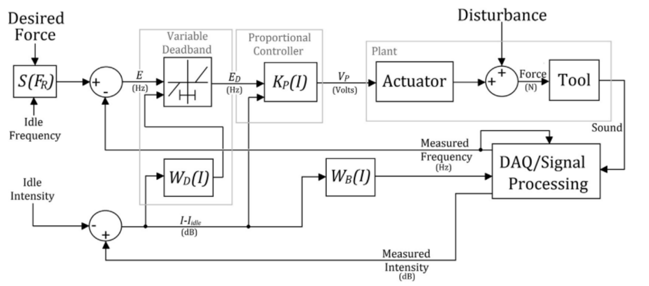

Figure 2. Close loop measurement control in machining (grinding) process [17]

2.3. *Measurement during the manufacturing process*

In the measurement during manufacturing, the product is measured and controlled by adding some additions to the machine tool (i.e. adding a measuring system) before the product is taken from the machine tool. This process is usually done before the product is completed and the final treatment (i.e. final pass) is applied according to the measurement result (Figure 3) [18]. In short, intervention is made before a situation outside the tolerance occurs.

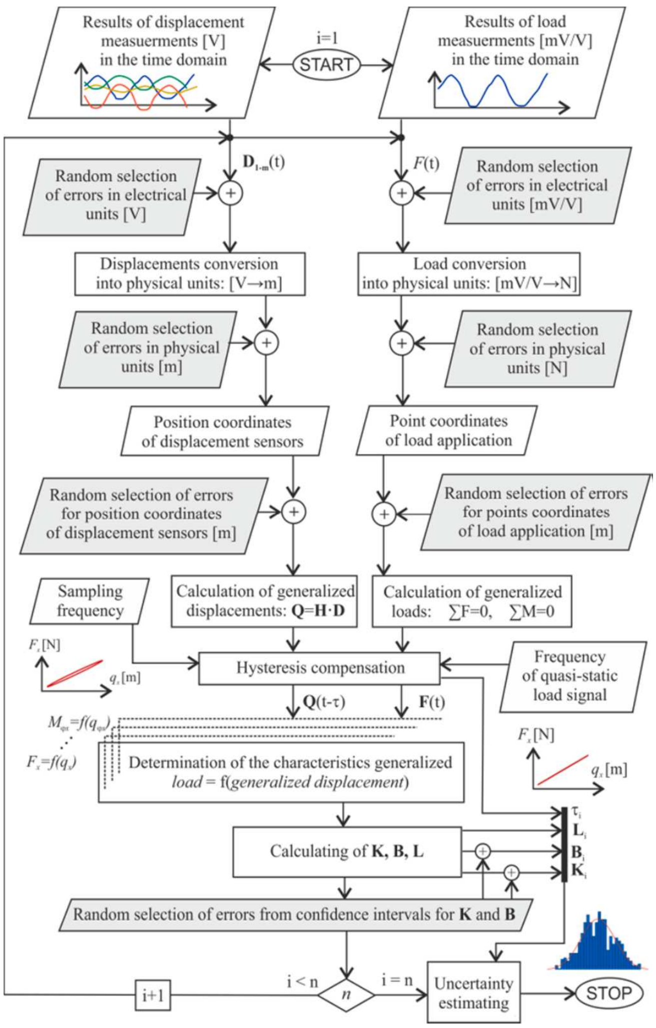

Figure 3. Monte Carlo algorithm for estimating the measurement uncertainty of quasi-static machine tool stiffness [18]

2.4. Advantages of measurement during the manufacturing process

The advantages of measuring the part and using the measurement data during the manufacturing process can be listed as follows:

• The biggest advantage when measurement is made during manufacturing is that revision can be applied in the final process on the part, since the problem is detected before the product is taken from the manufacturing environment. In other words, with the help of metrology, there is a positive intervention in production and the amount of scrap can be reduced. Since this process is done before the part is taken from the bench, the process of re-taking and adjusting the part, which causes high costs, is prevented. In the case of rework, time, cost and energy are significantly saved for the repositioning of very large complicated parts in the aerospace industry and large mold parts in the automotive industry [19].

• One of the most important reasons for making metrological analysis of manufactured products is to determine correction values for manufacturing and apply them to manufacturing. Since this capability will be on the machine tool with measurement during the process, it will be possible to make these corrections instantly with the data sent to the control of the machine. Since the measurement process is done on the machine where the product is processed, it is possible to do this several times at different stages of the process, and it is also possible to make very sensitive interventions to the production process [20].
• Since it is possible to use the production bench as a measuring bench, it is possible to make the final measurement of the product and report it instead of making a separate measurement. This seems to be a great advantage, especially for large and heavy items that are very difficult to transport [21].

• The performance of the machine tool during production, temperature, vibration, etc. changes due to external factors such as It will be possible to control the performance of the machine tool by measuring during the process and to make the necessary interventions in a timely manner [21].

3. MEASUREMENT METHODS DURING MANUFACTURING

The measurement methods to be used during manufacturing are determined according to the manufactured part. The following states of the part are taken into account.

• Geometric shape and simplicity of the part
• The effect of systematic error that can be controlled (i.e. temperature etc.)
• The size of the part and the complexity of the measured dimensions

Considering the studies done so far, we can classify the measurement methods to be applied during manufacturing as follows.

3.1. Direct measurement

Measurements are taken without reference to the bench in direct measurement, which is accomplished with the assistance of a measuring system that is positioned on the bench [22]. For example, during the production of train wagon wheels with classical lathes, while the part is being processed on one side, with the rotating encoder pulley system placed on the other side, finding the diameter of the part by using the circumference of the roller and the number of turns is one of the first examples that can be shown to measurement applications during the process. Non-contact measurement of the outer diameter of the part with the help of laser while the part is turning on the CNC lathe was realized. A laser Doppler distance sensor with phase evaluation (PLDDS) was developed and integrated into the CNC lathe for the measurement of the circumferential velocity, in other words, the circumference and diameter of the rotating part. The working principle of the developed system is shown in Figure 4 [23]. The biggest advantage of direct measurement is that the performance of the machine tool (error of axes, etc.) does not affect the measurement result [24]. The biggest disadvantage is difficulty to apply to complicated components.

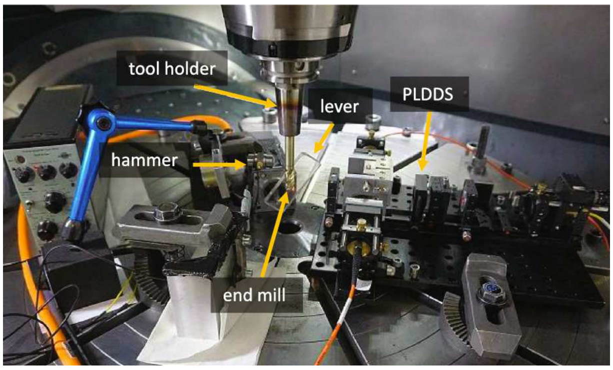

Figure 4. Direct measurement system in CNC machining [23]

3.2. Indirect measurement

In indirect measurement (Figure 5), the machine tool has an effect on the measurements made on the part. With a probe integrated into the machine tool, measurements can be made using the machine axes. Errors in the machine axes affect the measurement. In addition, calculating the effective parameters such as temperature, etc., estimating the correction values and making corrections with these values are indirect methods. The biggest advantage of indirect methods is that they allow the measurement of complex parts. The biggest disadvantage is that machine errors have an effect on the measurement [25].

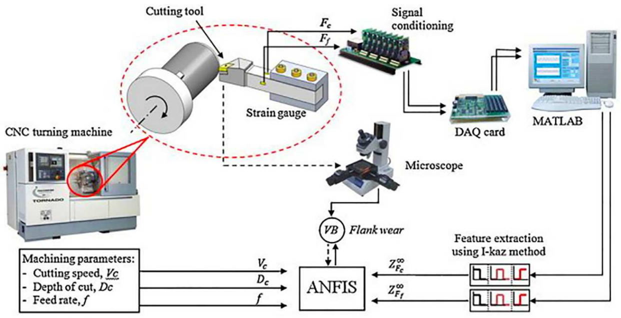

Figure 5. Indirect measurement procedure for tool condition monitoring [25]

3.3. Hybrid (Direct + Indirect) measurement

Today, many studies are carried out to make measurements during the process, such as direct measurement by removing the disadvantageous parts in indirect methods. The objectives here include calibrating and using the machine tool as a three-dimensional measuring instrument, integrating the appropriate probing and measuring system into the machine tool, and detecting and correcting machine tool defects with master parts. This method, which is used in the measurement and simultaneous processing of large complex parts, especially in the aerospace industry, is also becoming widespread in the automotive industry. Significant studies and researches are carried out on this method as it significantly reduces the cost and processing time. Figure 6 demonstrates a hybrid measurement method in machining process [26].

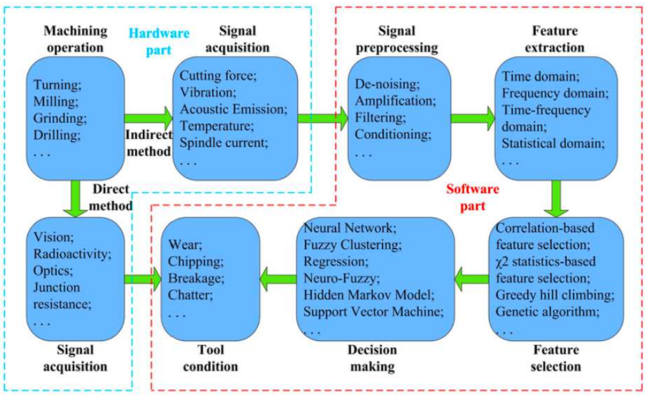

Figure 6. Hybrid (Direct + Indirect) measurement methods in machining process [26]

4. CONCLUSIONS

The main problems encountered in the machining of the most used materials in the aviation industry are that the surface roughness is not at the desired values and the deformation factor is high. The most important situation here is the accuracy of measurement during / after machining.

In-process measurement, which is increasingly preferred by companies due to its low manufacturing cost, high quality product, high efficiency, and instant evaluation of the quality of the product and production, is explained by taking into account the historical process. In this short review, the measurement techniques used are briefly explained with their advantages and disadvantages.

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