1. Introduction

Surface texture is an important function in enhancing aesthetic and tactile qualities and mechanical properties of products. The roughness of the product surface is generally textured by etching or sand-blasting. The amplitude of roughness is usually about several hundred µm. However, these manufacturing techniques have problems related to repeatability of manufacturing and environment pollution. To resolve these problems, we developed an exclusive system for generating surface texture by machining.

2. Generation process of surface texture

Fig. 1 shows the generation process of surface texture. This process consists of the following steps.

1) Measure the shape, waviness and surface trend of the specimen using a laser displacement meter.
2) Design the surface texture using the developed CAD system and map the designed texture to macroscopic data obtained in step 1) or designed geometrical shapes.
3) Generate the CAM data from CAD data.
4) Machine the specimen to generate the texture on the surface.
5) Measure the textured surface of the specimen using a confocal microscope system.
6) Assess the textured surface.
7) End.

Fig. 2 shows a systematic diagram of the surface texturing system. This system consists of a 3-axis milling machine with two spindles, control units, measurement instruments, laser displacement meter and confocal microscope, and CAD/CAM/CAT systems.
3. Surface texturing systems

CAD/CAM system

It is very difficult to design the surface texture using a commercial CAD system applying geometrical shapes. The developed CAD system can design random texture patterns such as human skin pattern and regular patterns such as fabric pattern like knitwear. The algorithm for designing random texture pattern is based on the arithmetic theory of 2D auto-regressive models [1]. When users want to design random texture, they must input the values of six parameters related to surface topography to the system, i.e. correlation length in the X and Y directions, multiplier of auto-correlation function, root mean square, skew, and kurtosis. The created random texture satisfies the statistical information defined by the six parameters. The user can also redesign the random texture pictured on the screen interactively by changing the parameters or using certain commands. On the other hand, a new algorithm for regular patterns was developed at our laboratory based on the theory of shape pattern recognition and self-assembly system, L-system, proposed by Lindenmayer [2]. The designed surface texture can be mapped to geometrical shapes designed on a commercial CAD system or surface data measured by step 1) of Fig. 1. Fig. 3 shows the texture image designed on the developed CAD system. Fig. 3(a) shows the designed texture pattern and Fig. 3(b) shows the texture pattern mapped to geometrical shape such as cylinder.

The developed CAM system can handle the CAD data mentioned above and contrast image data obtained from CCD cameras shown in Fig. 2. CAM data is generated to control the plane axis, X and Y, and height axis, Z, for the developed three-axis milling machine.

Milling machine

Fig. 4 shows the overview of the milling machine. This machine is controlled by 3 axis, X, Y, Z, and has two...
spindles. The specifications of the milling machine are as follows: Minimum X and Y axis travel is 10µm, Z axis is 1µm, and maximum spindles speed are 40,000 and 80,000 rpm respectively. The size of this machine is about 500mm(W)×400mm(D)×350mm(H).

Measurement system

A laser displacement meter system and confocal microscope system can be set up on the milling machine to measure the sample surface before and after milling. The laser displacement meter system is used to measure macroscopic surface information, shape, waviness and surface trend before milling. The measured macroscopic surface data is incorporated in the CAM data to mill the constant depth. Fig. 5 shows the overview of the laser displacement meter system and measured surface data. Fig. 5(b) shows that the surface trend of the specimen have been measured.

The confocal microscope system is used to measure the microscopic texture pattern after milling. As the image area taken by the confocal microscope system is small, the stitching technique is applied to broaden the area of surface texture. Fig. 6 shows the overview of the confocal microscope system and measured texture data. This system enables measurement of the machined surface by using the built-in optical microscope with CCD camera positioned in front of the spindles as shown in Fig. 6(a). The texture images are photographed continuously while changing the surface height. This microscope system allows selection of the focus pixels from these images by software to create the confocal image. Fig. 6(b) shows the measured texture pattern. Fig. 6(b-1) shows the cutter pass image of a human skin sample. Metal surface is machined based on its data. Fig. 6(b-2) shows the images taken by the confocal microscope system. As the image area of one shot is too small for assessing the machined texture patterns, macroscopic image is made by the stitching technique which can consist of many measured images. The result of stitching composed of the four images shown in Fig. 6(b-2) is shown in Fig. 6(b-3).

Finally the results of measuring the textured surface were compared with the CAD data and if there were inadequacies in milling, disagreement of surface height, etc., these flaws on the textured sample surface were milled again according to the CAD data shown in step 6) of Fig. 1. As a result, the textured surface and CAD data showed good
4. Experimental work

Basic experiments

Fig. 7 shows the basic experiments of milling. Fig. 7(a-1) shows the stage configuration produced by a flat-end mill. Fig. 7(a-2) shows the 3-D image measured by scanning white-light interferometer. The height of each stage is 3 \( \mu \text{m} \). The figure on the right shows grooves of 50 \( \mu \text{m} \) in depth at the intervals of 200 \( \mu \text{m} \). Both are well machined.

Results of surface texture generation

Fig. 8 shows the generation results of surface texture. Fig. 8(a) shows the anisotropic texture based on the CAD data of Fig. 3(a-1). Fig. 8(b) shows the isotropic texture of human skin photographed by the CCD camera. The table on the right shows each experimental condition. As shown in these examples, it is possible to produce extremely fine textures in the order of \( \mu \text{m} \) from various data. The developed milling machine can be said to be an efficient processing system for the generation of surface texture.

5. Conclusion

An exclusive system to generate the surface texture by machining has been developed. The system can design surface texture, perform milling in the \( \mu \text{m} \) level, and set up two measurement instruments to assess the surface topography of specimen. The technique applied in this system also allows generation of precision surface texture better than usual generation processes such as etching or sand-blasting.

References
