Fully automated measuring setup for tactile coordinate measuring machine for three dimensional measurement of freeform eyeglass frames

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Abstract. Coordinate measuring machines are high precision all-rounder in three dimensional measuring. Therefore the versatility of parameters and expandability of additionally hardware is very comprehensive. Consequently you need much expert knowledge of the user and mostly a lot of advanced information about the measuring object. In this paper a coordinate measuring machine and a specialized measuring machine are compared at the example of the measuring of eyeglass frames. For this case of three dimensional measuring challenges the main focus is divided into metrological and economical aspects. At first there is shown a fully automated method for tactile measuring of this abstract form. At second there is shown a comparison of the metrological characteristics of a coordinate measuring machine and a tracer for eyeglass frames. The result is in favour to the coordinate measuring machine. It was not surprising in these aspects. At last there is shown a comparison of the machine in front of the economical aspects.

1. Disadvantages of the tactile measurement of eyeglass frames

Difficulties of measuring objects like eyeglass frames are miscellaneous. For the most part of measuring challenges there is a detailed drawing or a target dimension of the device under test. In case of eyeglass frames, drawings are not free accessible and high manufacturing tolerances are given. Even an eyeglass frame has no fixed rules in form, design, material or dimensions. Thereby a lot of other problems like handling, fixing or even a mathematical model are not ordinary. These are the general disadvantages. There are even disadvantages because each tactile measurement method depends on contact and geometrical properties of the calliper and elected parameters.
These are reasons of the Department of Quality Assurance from the Faculty of Mechanical Engineering of the Technical University of Ilmenau promoted by the Federal Ministry of Economics and Technology within the framework of the InnoNet program to research for a new procedure for detecting deviations behind an undercut. An example about measuring an eyeglass frame is shown in figure 1. There you can see the stylus and the frame in three colours. There is a magenta area; this is the front side of a frame. There you can see a blue area; this is the backside of the frame. At last there is a small yellow area; this is the groove to measure. The groove is necessary to fix the special produced eyeglass lens. Also you can see the main problem. The frame can be anywhere in the area of the coordinate measuring machine and is variable in all three dimensions. Without advanced information about the measuring object, the increase of measuring-time to measure the whole area would be unacceptable.

2. Assumptions to measure an eyeglass frame

A simplification in figure 2 shows important information to measure an eyeglass frame with coordinate measuring machines. Every frame has a groove for carrying the eyeglass. This groove is V-shaped with an angle of 120 degree and a depth from 150μm to 450μm. Barely these circumstances of the groove make an automatic scanning with coordinate measuring machines possible. The basic idea is to adjust the direction of force outward and along the bias of the groove. This is even shown in figure 2.

To get a continuous three dimensional curve of the whole eyeglass frame it is necessary to scan along the groove. This is not able to realize, but it is able to scan on upper and lower side of the groove. The direction of force on the upper side is inverse to direction of force on the lower side. If the scanning
process of the forces is always between these two directions, it has to be able to stay into groove during scanning process. This is a solution for coordinate measuring machines to stay into groove of device under test. In fact the ground of the groove is the intersection line of the upper and lower side. Even only ball-calliper is used; consequently the needed ground of groove is able to calculate. To get sense of force, a model of a circle is the base of measuring procedure. Although an eyeglass frame is not a circle, it is a free and convex form, so the sense is always from centre to outside. This is shown in figure 3. Here you can see magenta the circle for sense and green / yellow, points of the scanned groove. As you can see, absolute deviation and departure from circularity is high. To avoid measuring deviation, tolerance-parameters have to be chosen very high and measuring speed adequate low, to prevent flipping out of groove. A lot of other parameters of the scanning process, which should not be described here, have to be adjusted too. The results in face of metrological aspects should be shown in next chapter.

3. An example of technological solution of an eyeglass-frame-tracer

To explain the method of usual eyeglass-frame-tracers a figure of a patent [4] should be used. All founded available tracers on the market are using the same principle. As shown in figure 4 a stylus is routed by the groove. The mentioned stylus has the identification number 33. Because the balance point of the stylus, it is always vertical adjusted to the form. The stylus is flexible in his height, so the third dimension can be selected without using a drive system. Also shown in figure 4 is an arrow with the identification number 49.

![Figure 4. measuring-system of a tracer [4]](image)

The arrow shows the direction of movement of the carriage, which maintains the stylus. The direction is always to the outside during the whole construction is rotating about himself. By the rotation about 360 degree, the movement of the carriage to the outside and the height of the stylus you can get all three dimension.
The three dimensions are not Cartesian coordinates, but in polar coordinates. A conversion between both of them is simple math. As you can see, it is measuring principle. There are only two driving units and three measuring units.

4. The results in metrological aspects of coordinate measuring machine an eyeglass-frame-tracer

To compare both measurement systems a constant device and an eyeglass frame was used. The constant device confirms the geometrical primitive of a planar circle and an ellipse form which is not planar. One device is planar for this reason of comparability in two dimensions. The non-planar has a curve like a giant sphere, like an eyeglass-frame would have. So the comparability in favour of the third dimension should be given.

The important measurement variable and crucial indicator of eyeglass frames is the circumference of the groove. This is consideration of manufacturing of the eyeglass for the associated frame. An eyeglass is not of a flexible material, mostly. The eyeglass-frame is mostly of flexible materials, but it is a closed form. For this reason, the form of an eyeglass-frame can be changed, but not the circumference of the closed form and soon the important a comparable variable is circumference. Circumferences of the eyeglass and frame have to be exactly the same.

The special method to calculate the circumference should not be described here.

The following table 1 shows manufacturer's data, results of measuring a tube with a groove and the ellipse frame for measuring 25 times.

| Table 1: results of practical measurement [2] |
|-----------------------------------------------|-----------------------------------------------|
| Coordinate measuring machine | Eyeglass frame tracer |
| Measurement range | 400x400x200mm³ | 70x150x30mm³ |
| Accuracy (DIN EN ISO 10360-2) | MPEₚ = 1,9 μm | (no information) |
| Tube with a groove | | |
| Arithmetic mean | 141.3716mm | 140.8581mm |
| Standard deviation | 0.001mm | 0.0250mm |
| Nominal range | 0.002mm | 0.0566mm |
| Ellipse frame | | |
| Arithmetic mean | 150.7039mm | 152.2694mm |
| Standard deviation | 0.0071mm | 0.0333mm |
| Nominal range | 0.0192mm | 0.1465mm |

This short conclusion of the metrological results shows very good results for booth measurement systems. At the tube with groove the standard deviation of the coordinate measuring machine is as low as accuracy. The absolute difference of ~0.5mm between both systems is not notable, because the circumference of 0.5mm equals a radius of only 0.079mm. The difference of the circumference at ellipse frame is much more respectable. The difference of the mean circumference is grown 3 times higher from 0.5135mm up to 1.5655mm. The standard deviation of coordinate measuring machine grows up to 7 times and nominal range up to 9.6 times. The standard deviation of the eyeglass frame tracer grows up to 1.33 times and nominal range up to 2.59 times.

At all the coordinate measuring machine delivers in front of measurement parameters much better results in opposite of the eyeglass frame tracer. Interesting is the difference of the statistical results of a planar and non-planar device. Here the eyeglass-frame-tracer provides better results. Reasons of the different multiplication of both systems in case of the third dimension are multifaceted. Fundamental the mounting at coordinate measuring machine is not specialized; the forces are too high.
for mounting. Even the radius of stylus is too high for this little groove. The minimal radius of radius is given by groove. It has to be higher than depth of groove, because of case of shaft touch.

5. Comparison of economical aspects of coordinate measuring machine an eyeglass-frame-tracer

The comparison of the economical aspects is not simple. There are a lot of aspects which are addicted to application and adoption. A short conclusion should be given in table 2. Only costs about acquisition and deprecation are given quantitative. Other aspects are only shown qualitative.

Table 2: Short form of the economical aspects [3]

| Attribute / costs                  | Coordinate measuring machine | Eyeglass frame tracer |
|-----------------------------------|------------------------------|-----------------------|
| Acquisition costs                 | 150000€                      | 2500€                 |
| Depreciation                      | 6 years                      | 6 years               |
| Development costs                 | High                         | High                  |
| Transport costs                   | High                         | Low                   |
| Installation costs                | High                         | Low                   |
| Personnel costs                   | High                         | Low                   |
| Maintenance costs                 | High                         | Low                   |
| Material costs                    | High                         | Low                   |
| Staff training                    | Yes                          | No                    |
| Chance to upgrade                 | Yes                          | No                    |
| Measuring time                    | 60 sec                       | 20sec                 |
| Standard Deviation                | 0.0071mm                     | 0.0333mm              |
| Nominal Range                     | 0.0192mm                     | 0.1465mm              |

6. Conclusion

At all there was shown the foundation of one measurement setup for fully automatic three dimensional measurements of freeform eyeglass frames. The special requirements about measuring such device are the geometrical details of the device under test. Without the given groove, there would not be any force for direction of the scanning stylus by using coordinate measuring machines and an automatic measurement would not be able. A three-dimensional scanning measuring procedure by detecting several forces by aspiring a circle is the solution at coordinate measuring machines. This procedure has the quality characteristics of very low standard deviation, but high measuring time and very high costs at all.

Also there was shown a measuring principle of specialized eyeglass-frame-tracer even using the geometrical facts of groove. Here even a three-dimensional scanning measuring procedure is the basic principle. Significant is the order of action; at first direct positioning up to a limit of force and at second measuring the encoder or like eyeglass-frame-tracer by measuring the encoder all the time. Therefore the eyeglass-frame-tracer is much faster than used coordinate measuring machine at this setup and because of much less adjustment control not that expensive. A small drawback in standard deviation is an effect.

This effect can be tolerated, because the grinding machine for eyeglasses is not much more accurate. Also it was shown, that the results absolutely are comparable, even if they are affected by many different system-parameters.
References

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