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MEASUREMENT OF THE DISCHARGE PORT FOR A SCREW COMPRESSOR

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ABSTRACT

Much design, machining and measurement effort has been directed towards the rotors themselves, in a screw compressor (helical lobed compressor). This paper deals with another important feature of the screw compressor - the axial discharge port. Geometric tolerancing of the discharge port is discussed. The discharge port was modeled on a CAD system. The CAD data was transferred into a CMM (Coordinate Measurement Machine) with scanning capabilities. The measurement data was collected and the actual discharge port profile was reconstructed using the CMM software. Comparison was made with the nominal profile by visualizing each segments' deviation, taking the datums into account. Gauge repeatability and reproducibility were discussed, as well as profile form machine settings.

INTRODUCTION

The function of the discharge port on a screw compressor is to provide an exit of the gas/oil from the flutes of the rotors. The beginning of discharge from the flutes at a given volume of the flutes gives the volume ratio of the compressor. An error in this area would give different than intended volume ratio, which could mean a loss in adiabatic efficiency. At the end of the discharge of the flutes volume, the port helps to complete the drain of the flutes without opening connection to suction. This means that if the port is not correct in this area, so the flutes are not completely drained before the port closes, over compression is going to take place until the gas squeezes through the rotor end-play or through the rotor mesh, taking extra power consumption. If mainly oil is trapped when the flutes are not completely drained, compression of incompressible fluid will be attempted, giving imbalance, commonly called "rotor rattling". If the port opens up towards suction, there will be lowered suction flow rate. With increased capability to machine and measure rotors, housings regarding true position and diameter, high precision bearings and small rotor end-play settings, the time has come to evaluate the axial discharge port in detail.

DIFFERENT WAYS TO MAKE THE DISCHARGE PORT

The most common is to cast the entire axial discharge port, possible with an extra machining on one side of the tongue, facing the female rotor. The entire port can also be machined, either milled or with EDM. The port measured in this paper has the entire edge facing the rotors machined with an end-mill. The theoretical port has to be simplified depending on manufacturing method. The simplified port is the nominal port during measurement evaluation and the actual port is compared with the nominal port.

GEOMETRICAL TOLERANCING OF THE DISCHARGE PORT

Figure 1 shows the geometrical dimensioning of the nominal discharge port that will be scanned. Datum A is the face of the discharge housing facing the rotors. Datum B is the male rotor bearing bore (the top or left bore in figure 1). Datum C is the female rotor bearing bore (the bottom or right bore in figure 1). Profile form of a surface has been used. The total tolerance range m is a function of rotor end-play, rotor tip speed and the relative size of the compressor. The tolerance range n is smaller than m, since it affects the final drainage of the port. Usually n = m/2. Figure 2 shows reference data for CNC programming and CMM measurement. The different coordinate points are mainly tangent points and they can be derived from figure 1. To actually show those points is practical, so exactly the same numbers with the same accuracy is used to program both the CNC machine and the CMM. Coordinates (X1,Y1), (X2,Y2), (X4,Y4) and (X6,Y6) are used to specify the different profile form tolerance ranges. Coordinates (X3,Y3) and (X5,Y5) are machine adjustment reference points.
DIFFERENT WAYS TO MEASURE THE DISCHARGE PORT

For a casted port a simple lay-out based on the most important features such as radii etc. is normally performed to qualify new casting tools. Different optical systems can also be used as well as a CMM in touch probing mode or scanning mode.

CMM MEASUREMENT OF THE DISCHARGE PORT

A coordinate measuring machine (CMM) is a commonly used tool in industry to measure features of size and also to evaluate geometric tolerances such as position, perpendicularity etc. They are available in a wide range starting from the touch trigger models which are used more commonly to the high accuracy machines with the analog probe for more specialized applications like gear and rotor measurement.

A commonly adopted practice in measurement of a feature such as the discharge port would be to evaluate the tolerances in relation to the accuracy of the machine with which the measurement would be done. In practice the 8:1 rule is commonly used i.e. the tolerance on the feature should be at least 8 times the accuracy of the machine. Another important feature is to identify capabilities of the CMM software without which it is difficult to measure this feature. The software should for instance be capable of handling the actual probing points of the measured feature separately which gives a lot of flexibility for radius correction and actual nominal comparison. The software should also be capable of constructing curves or contours from the measured data using cubic splines or any other algorithm. Typically the features mentioned above are found on CMMs with scanning capabilities. Measurement of such profiles would also require large point density in order to calculate the curve. A CMM with scanning capabilities would be better suited for the purpose and would also be much faster for measuring such a feature as compared to probing single points on the profile which could take a longer time.

The measurement process as such is completed in three steps. The first step would be to build a nominal geometry either within the software or to import the nominal data in some form into the software with which the comparison is made. In this case CAD data was imported from a CAD software and also the nominal profile was constructed using the CMM software. The CMM software in most cases, will offer the flexibility of constructing two dimensional elements from the Cartesian coordinates or the ability to construct elements as a combination of arcs and line segments if the nominal lengths and radii are known.

The next step is to measure the actual profile of the port. In this case the port was measured as separate segments and later combined to form one feature. This would also determine the kind of probes and calibration needed for this particular feature. Scanning parameters such as speed and point density are determined based on the curvature of the surface being measured. The cycle time for measurement of this port was about 5 minutes, including datums. Only closed loop scanning was used in this case. The port was scanned as a two dimensional feature because essentially we were concerned about the relation of the port to the datum bores. All the measured points were then collected into a single two dimensional feature. Most CMMs store center of ball coordinates which need to be compensated for the probe radius. In standard features such as circles this is done automatically. But in the case of contours like the discharge port the CMM software will want the input from the user for the direction of the radius correction. The user has the option of inputting different parameters for the radius correction like direction of the curve, whether the curve is clockwise or counter clockwise, etc.

The third and final step would be to perform an actual to nominal comparison to see how well the actual measured profile compares with the nominal profile. Fig. 3 (corresponds to profile tolerance range m on fig. 1) illustrates the measurement results obtained from an initial setup part. Fig 3 shows some portions of the profile fall outside the tolerance band. Coordinates on the NC machine could be adjusted and also issues such as speeds, feeds, tools and fixturing could be looked into in order to obtain a better form on the whole profile. Fig. 4 (corresponding to profile tolerance range m on fig. 1) indicates the measured profile after corrections were incorporated on the machine tool. As we can see the profile form is much better and is within the tolerance band. Clearly the measured profile would provide an indication of how much the tool should be offset and in which direction. It would also be useful in cross checking if the right numbers were input for the tool coordinates.

The measured profile could also be best fitted onto the nominal profile in which case the measured profile would be shifted in X or Y directions or just be rotated about the Z axis (an axis perpendicular to the

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measuring plane) so as to minimize the deviations to the nominal. This is done using commands built into the software. This is perhaps the most important step in the whole process. The results from best fit could be used to correct for the machine tool or the fixture that holds the part. The best fitting with all degrees of freedom i.e. translation and rotation is usually performed when only the form of the profile is critical and not the location relative to datums. In some cases the best fitting is done with only rotation and no translation. The main aim of best fitting is to remove alignment errors and also location errors from the actual nominal comparison. An actual nominal comparison could be done after the best fit and can be compared to the results obtained before the best fitting is carried out. The method for machine setup shown on fig. 2 coordinates (X3, Y3) and (X5, Y5) utilizes X and Y shift obtained from the best fit.

In any measurement process the term repeatability and reproducibility assume importance in order to validate the process. How does one keep track of repeatability in this case? One way would be to measure the same profile several times and make sure the probe gives similar results, but still it is difficult to judge the repeatability of the measurement or the process capability with this. The method that was adopted in this case was to use identification points on the profile and to keep track of these points in subsequent measurement runs. This proves to be a useful concept particularly in case of curved contours. The identification points could be chosen based on the functionality of the profile and could be used to keep track of the process capability index CpK. These points could be used for statistical process control (SPC), and thereby determine the frequency of measurements depending on the process capability. These identification points could also be used to perform a gauge repeatability and reproducibility study.

CONCLUSIONS

The CMM proves to be a useful tool in evaluating the profile such as the axial discharge port. The measurement process is not only intended for verification but could also be used for troubleshooting. For instance, incorrect setup of the part and tool wear or chatter could be detected early before it poses a real problem. To more accurately measure and machine the discharge port opens up possibilities to improve the performance of the screw compressor as well as minimize the chance for rattling rotors.

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REFERENCES

FIGURE 1.
REFERENCE DATA FOR CNC PROGRAMMING AND CMM MEASUREMENT

NOTE 1: COORDINATE DIMENSIONS (X3-Y3) AND (X5-Y5) ARE MACHINE ADJUSTMENT REFERENCE POINTS. USE POINT (X3-Y3) TO ADJUST X VALUE AND USE POINT (X5-Y5) TO ADJUST Y VALUE.

FIGURE 2.
FIGURE 3. MEASURED PORT BEFORE CORRECTION
FIGURE 4. MEASURED PORT AFTER CORRECTION