OPUS-HSO

Repositorium der Hochschule Offenburg
https://opus.hs-offenburg.de

Thread cutting and data analysis using a vertical articulated robot

Markus Gapp, Jennifer J. Blöchle, Thomas Wendt, Stefan Rupitsch

Zitiervorschlag im APA Stil:

Gapp, M., Blöchle, J. J., Wendt, T., & Rupitsch, S. (2024). Thread cutting and data analysis using a vertical articulated robot. *22. GMA/ITG-Fachtagung Sensoren und Messsysteme 2024*, 516–519. https://doi.org/10.5162/sensoren2024/P24

Abstract

The objective of this work is to automate thread cutting of internal threads using an industrial robot. The system is designed to accommodate various sheet sizes based on the robot's working range. The robot controller records the data of axis 6 during the cutting process, which will be applied for process and quality analysis. This axis was utilised for the cutting process. An optical displacement sensor determines the accuracy of the moving axis. The robot's endlessly rotating axis 6 offers further advantages, including no additional drive for cutting, maximum flexibility, high automation, and a large working range of up to 800 □ 800 mm depending on the robot. The maximum torque derived from the cutting process was 3.52 Nm. The radial movement of the chuck was measured at Δr = 0.27 mm, which was 60 times higher than the planned data.

Nutzungsbedingungen

Dieses Dokument wird unter diesen Bedinungen zur Verfügung gestellt:
Creative Commons - CC BY-NC-SA - Namensnennung - Nicht kommerziell - Weitergabe unter gleichen Bedingungen 4.0 International
Für weitere Informationen siehe:
https://creativecommons.org/licenses/by-nc-sa/4.0/deed.de

Kontakt

Hochschule Offenburg | Bibliothek
Badstraße 24
77652 Offenburg
Telefon: (0781) 205-240
E-Mail: bibliothek@hs-offenburg.de
www.hs-offenburg.de/bibliothek

Thread cutting and data analysis using a vertical articulated robot

Markus Gapp[1], Jennifer J. Blöchle[1], Thomas M. Wendt[1], Stefan J. Rupitsch[2]
[1]Hochschule Offenburg, Badstraße 24, D-77652 Offenburg
[2]Universität Freiburg, Institut für Mikrosystemtechnik – IMTEK, Georges-Köhler-Allee 201 D-79110 Freiburg
Tel. 0781 205-1130, markus.gapp@hs-offenburg.de

Abstract

The objective of this work is to automate thread cutting of internal threads using an industrial robot. The system is designed to accommodate various sheet sizes based on the robot's working range. The robot controller records the data of axis 6 during the cutting process, which will be applied for process and quality analysis. This axis was utilised for the cutting process. An optical displacement sensor determines the accuracy of the moving axis. The robot's endlessly rotating axis 6 offers further advantages, including no additional drive for cutting, maximum flexibility, high automation, and a large working range of up to 800 · 800 mm depending on the robot. The maximum torque derived from the cutting process was 3.52 Nm. The radial movement of the chuck was measured at Δr = 0.27 mm, which was 60 times higher than the planned data.

Keywords: Robotics, thread cutting, data analysis, process quality, robot accuracy.

Introduction

Manufacturing processes in general are categorised into four main groups: primary shaping, forming, cutting, and special processes [1].
Similarly, thread production is categorised into primary shaping, forming, and cutting, and is part of the special processes. Table 1 illustrates the categories of the cutting processes.

Tab. 1: Cutting processes for thread production [1, adapted].

Thread cutting processes		
With a geometrically defined cutting edge	With a geometrically non defined cutting edge	Erroding

Recent research focuses on thread cold rolling with round dies [2], a highly efficient and quality-oriented forming process. Cold rolling is established in various industrial fields for outside threads, such as shafts.

Automation allows for various methods of thread cutting, including manual processes, semi-automated processes with thread cutting arms, and fully automated processes using machines such as milling cutters, CNC, or punch laser machines.

This innovative solution bridges the gap between semi-automated and fully automated machines. Our robot is capable of automating the process without the need for an external drive. By utilizing the last axis of an articulated robot, we eliminate the need for a special electric motor for cutting.

The metal sheets in this case are prepared for M4, M6, and up to M12 threads. This work specifically highlights the cutting of M4 and M6 threads.

System setup

This contribution discusses the use of the endless rotary axis 6 for cutting threads with a geometrically defined cutting edge [1], as opposed to using a special drive for drilling [3] or cutting.
Therefore, this approach offers a flexible design that is particularly helpful for smaller quantities. Furthermore, the data from the cutting axis will be analysed to draw conclusions about the process and quality. Figure 1 shows the system setup, including the sheet holder, sheet, flange-mounted thread cutter, and the KUKA KR16 industrial robot.

The size of the sheet metal is 289 · 248 mm and the length of the thread cutter is 60 mm, as shown in Figure 1.

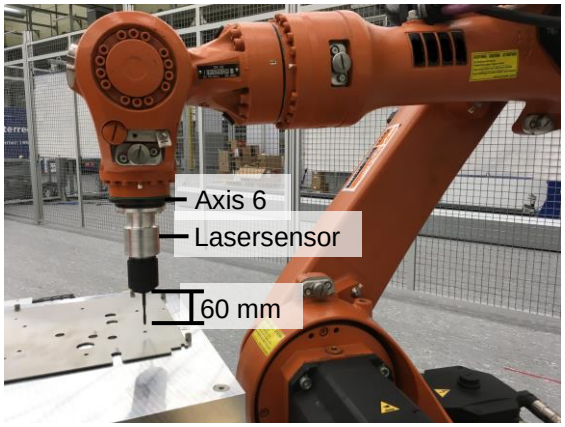

Fig. 1: System design and setup, thread cutter flanged directly onto the endless rotary axis 6.

Data collection and methods

The operating range of robot axes is mechanically limited, which also defines the working range of the kinematics. Only axis 6 does not have a mechanical end stop and can be configured as an endlessly rotating axis.
The robot controller offers various information through the oscilloscope function, such as path planning data or drive measurement data. It is also possible to store system parameters. This is done at 12 ms intervals (83 Hz), the drive measurement data is recorded at 500 Hz.
The process of triggering can be initiated by a direct call from the robot program. The data to be recorded needs to be configured in advance.

The so-called interpolator data and the data from the robot's cutting axis 6 are particularly interesting for this task. The interpolator data is based on path planning calculations, for example using forward [4] and backward transformations. These include the Cartesian values and, for example, the electric current, speed and tracking error of axis 6, all of which can be displayed on the robot controller's teaching box. These values can also be accessed in files and processed offline using software packages like Matlab.

Figure 2 displays the Cartesian coordinates of the interpolator data. The movement in direction of the sheet metal equals 8 mm in z-direction of the robot's base coordinate system. From the starting position above the hole, the depth of a cut can be ensured if the thread cutter is functioning properly and not broken.

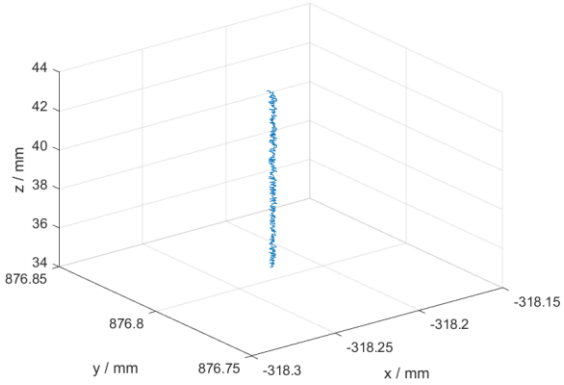

Fig. 2: Interpolator data x, y and z from the path planning. Minor deviations are visible due to the resolution in the calculation.

The position of the axis 6 movement between the robot's flange and the drill chuck was measured using the laser distance sensor (Sick OD2000-1301T15) as shown in Figure 1. The distance was calculated based on the sensor's working range using the analog voltage output, which was measured with a data acquisition device from Measurement Computing (USB1208LS).
The differential method was used at a sampling rate of 1000 Hz.

Results of process torque

Figure 3 shows the torque of the cutting axis with (red) and without (blue) material processing for an M6 thread. The increase in torque at the start and during cutting is evident. The thread depth is << 1.5 · *D*, where *D* is the diameter of the M6 thread, and therefore there is no relaxation problem [5]. The areas of feed (1), forming (2) and shaping (3) are also visible in the electric current and torque of axis 6 [6]. At the end of range (3), there is a slight decrease in torque, which is caused by the already cut sheet metal.

The torque of axis 6 at the robot's flange can be presented as

$$T_{(l)} = i \cdot kt \cdot I \qquad (1)$$

where *i* – gear ratio
kt – motor constant
I – motor current

The torque to process the thread cut corresponds to

$$\Delta T = T_P - T_M \quad (2)$$

$$\max(\Delta T) \quad (3)$$

with T_P – torque including cutting process
T_M – torque to move only the axis without processing

The signal noise [7] is a result of the current measurement.

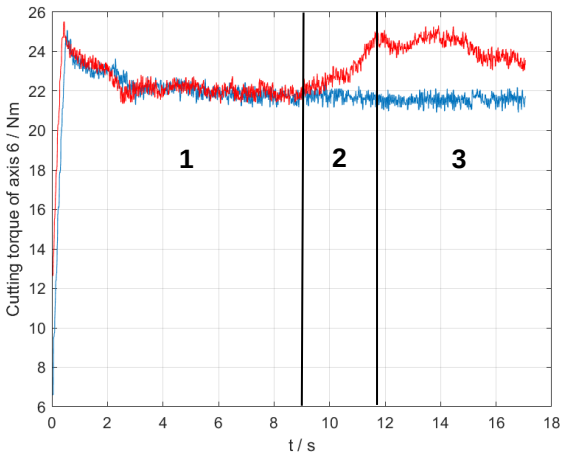

Fig. 3: Comparision of torques, movement without cutting and with cutting a thread at the output/flange of axis 6.

Results of gradient, range (2)

The cutting torque gradient (dT/dt = 1 Nm/s) was derived from Figure 3. This could be used for quality control in addition to the maximum torque value.
The gradient depends on the cutting speed of the thread cutter and must be adapted to the speed and the material to be cut, which is not the subject of this work.

Results of radial spindle accuracy

Figure 2 displayed the planned path during thread cutting, as indicated by the interpolator data. The measurement was executed while cutting a thread. Figure 4 illustrates the radial movement of the chuck during thread cutting.

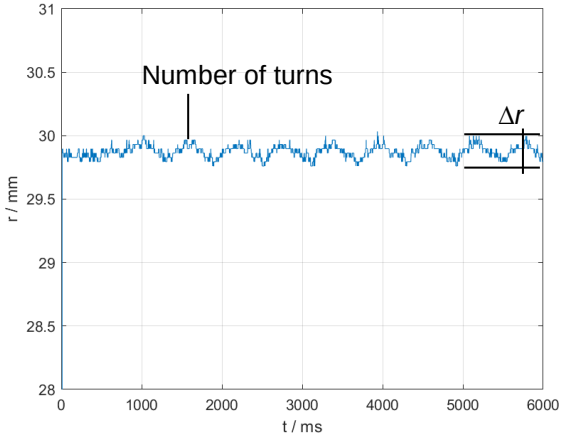

Fig. 4: Radial accuracy, the movement of the drill chuck has been programmed as shown in Fig. 2.

The maximum values are obtained from each rotation of the drill chuck. The sensor analog voltage signal is always utilized within the range of 0 to 5 V, which corresponds to a range of 60 to 130 mm. Therefore, the values displayed above indicate a distance of approximately 90 mm between sensor and chuck.
The remaining peaks are a result of optical sensor measurements caused by reflections on the metal surface. Although a transversal filter is used to filter the signal, some minor peaks are still visible.

Discussion

Threads smaller than M6 do not show a significant increase in torque. Measurements of M4 cuts showed a maximum process torque of only 1 Nm. This is due to the lower torque required to cut an M4 thread in a 2 mm thick sheet compared to the torque required to move the spindle alone.

The torque required to cut an M6 thread can be determined from the process torque graph, as shown in [5]. The maximum torque value recorded was 3.52 Nm, calculated using equations (1), (2), and (3). The data are presented in Figure 3.

The increase in torque during forming the thread, refer to range 2 in Figure 3, ensures the correct cut.

Upon analysing the interpolator data during thread cutting, it was found that there is an inaccuracy in the radius r of Δr = 0.0043 mm (calculation based on Figure 2). Additionally, a Δr = 0.27 mm was measured by observing the radial movement of the chuck. These findings

suggest that the robot's geometric model is inaccurate due to a lack of calibration.

Conclusion

It has been demonstrated that the setup can cut threads in a sheet metal using only axis 6 as the spindle of an articulated robot.
Due to the large working range of the robot, it is possible to work on sheets up to 800 mm wide.
The torque for the cutting process can be calculated from the electric current of axis 6. Figure 3 shows distinct torque curve regions as described in [5].
The spindle's accuracy during the cutting process was measured and compared with the calculated values. The chuck's measured accuracy was 60 times worse than the planned motion, indicating that the robot is not an absolute calibrated robot [8]. This is compensated in the given system setup by the mechanical backlash of the drill cutter shaft.

Further research is required to investigate the effects of different thread sizes. For threads smaller than M6, the main focus should be on detecting the process torque. Conversely, larger threads, such as M12, could have a significant impact on kinematics resulting from process torque. This is particularly relevant when the robot arm is operating at the outer limits of its working area. The significant difference in eigenfrequency between the inner and outer ranges could have an impact on the quality of thread cuts.
The suggested measurement setup has revealed a difference between the Cartesian data of the path planning and the radial movement of the chuck, highlighting the importance of accuracy in robotics. It is assumed that the main factor affecting accuracy is the partially calibrated robot.
Further research is required to determine whether a geometrically calibrated robot would perform better. Additionally, it is of interest to investigate whether measuring axis 6 with a single displacement sensor is a viable method for verifying the robot's accuracy.

The proposed setup offers a fully automated and cost-effective solution that surpasses existing machine solutions.

Acknowledgement

We would like to thank Co. Ruch Novaplast GmbH for sponsoring the robot and Co. Förster Technik GmbH to support us with thread cutting equipment.

References

[1] B. Bender, D. Göhlich, Dubbel Taschenbuch für den Maschinenbau, Band 2, (2020); doi: 10.1007/978-3-662-59713-2_1
[2] D.-W. Zhang, C. Zhang, C. Tian, S.-D. Zhao, Forming characteristic of thread cold rolling process with round dies, The International Journal of Advanced Manufacturing Technology 120:2503–2515 (2022); doi: 10.1007/s00170-022-08918-6
[3] J. Arthur, M. Khoshdarregi, Pose optimization and path improvement in robotic drilling through minimization of joint reversals, Taylor & Francis, Advanced Robotics, 36:20, 1076-1086 (2022); doi: 10.1080/01691864.2022.2125828
[4] L. Zhibin, L. Shuai, L. Xin, An Overview of Calibration Technology of Industrial Robots, IEEE/CAA, Journal of Automatica Sinica (2021); doi: 10.1109/JAS.2020.1003381
[5] R. Bienemann, Evaluation der Schneidkantenbelastung beim Gewindebohren schwer zerspanbarer Werkstoffe, Dissertation, Universität Kassel (2009)
[6] M. Schäfer, Analyse und Beschreibung des Innengewindefertigungsverfahrens Gewindefurchen auf Basis eines Modellversuchs, Dissertation, Universität Kassel (2004)
[7] R. Kunzler, Rotorlagegeberlose Verfahren zum Betrieb einer permanenterregten Synchronmaschine im elektrifizierten Antriebsstrang, Dissertation, Universität Magdeburg (2018)
[8] A. Nubiola, I. A. Bonev, Absolute calibration of an ABB IRB 1600 robot using a laser tracker, Robotics and Computer-Integrated Manufacturing 29 (2013), doi: 10.1016/j.rcim.2012.06.004