Sebastian SCHMIDT[1*]
Eberhard ABELE[1]

INTEGRATION OF DISCONTINUOUS MILLING OPERATIONS INTO THE FLOW PRODUCTION OF SHEET METAL PROFILES

This paper is about the integration of discontinuous milling operations into the continuous flow production line of branched sheet metal profiles in an integral design. A major challenge is the non-existing possibility to clamp the work piece due to its constant feed. The machining "on the fly" itself is only possible through synchronizing the movement of the machine tools axes with the continuous feed of the sheet metal profile.

1. INTRODUCTION

Bifurcated structures such as plants or bones are very essential for a lot of applications in design of automobiles, machines, buildings etc. Typical examples for bifurcated structures are multi-chambered profiles, which are used as elements of lightweight construction in various fields of engineering. The demand for increase in productivity and the use of potential lightweight construction is the motivation for the research of the Collaborative Research Center (CRC) 666 at the Technische Universität Darmstadt (TUD). The superior goal of the CRC 666 is to generate bifurcated structures in integral design from steel sheet bands by means of novel production methods and techniques. Amongst others the novel manufacturing process linear flow splitting is used [1]. The research work covers the complete product development process, starting with the definition of the requirements, over product design and manufacturing to product testing.

The manufacturing process consists of forming, machining, joining and cutting processes. The production line is based on a modular system to arrange the machine modules in different sequences. By the means of the CRC 666 production line sheet metal constructions in the usual differential, multiple component design can be replaced by an integral, consisting of a single piece design. Function and stress-optimized geometries can be manufactured specifically. Figure 1 shows two examples of components produced by the CRC 666 production line.

---

[1] Institute of Production Management, Technology and Machine Tools (PTW), Technische Universität Darmstadt, Germany
[*] E-mail: s.schmidt@ptw.tu-darmstadt.de

Fig. 1. Multifunctional sheet metal profiles produced by the CRC 666 production line

The High Speed Cutting (HSC) sheet milling process is an essential part of the production line. Compared with other production processes like stamping the HSC milling has the advantage to manufacture various continuous and discontinuous form elements. Furthermore the machined milling features can be changed quickly and cost effective without additional material requirements.

Discontinuous in-line milling operations in continuous flow production of metal profiles are not state of the art. In case of a designated milling operation, it is done after the cutting process by separate machine tools. The integration of discontinuous milling operations into the continuous flow production enables the retrenchment of those downstream operations to save the necessary material handling, production time and costs. As a consequence the costs of the metal profiles can be reduced.

2. SYNCHRONIZATION OF THE MACHINING PROCESS WITH THE CONTINUOUS WORK PIECE FEED

The milling process is performed by a specially built gantry milling machine tool (see Fig. 2). This machine tool offers a traversing range of 7 m in directory of the work piece feed which is up to 50 m/min. To perform milling operations on a moved work piece, the machine tool needs to provide high dynamic machine axes. The gantry reaches an acceleration of 17 m/s² and a velocity of 120 m/min in work piece feed directory, which enables the gantry to run ahead the work piece [2].
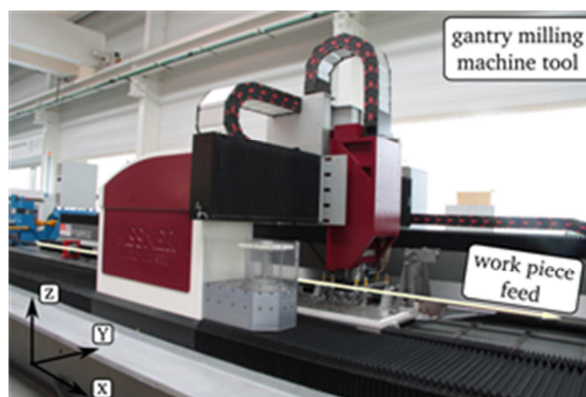

Fig. 2. Wissner WiTEC 7013 SFB gantry milling machine tool

During stationary milling operations the work piece is clamped. This ensures its proper fixation under the influence of machining process forces. In contrary to stationary milling operations the continuous work piece feed mustn't be stopped during the machining operation, which would cause an interruption of the continuous flow production. So the possibility of a conventionally work piece clamping during the milling operations is not given. For this reason a specially built material guiding system was developed [3]. It guides the work piece in the machining area (see Fig. 3).
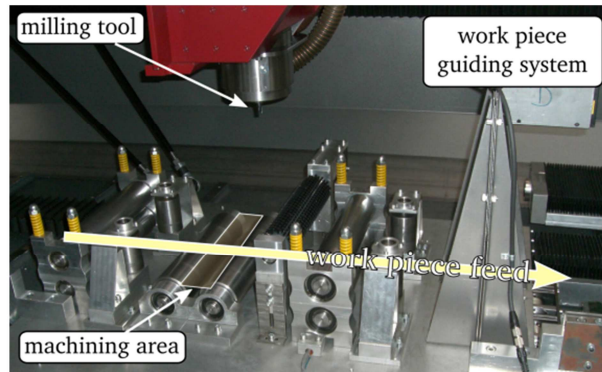

Fig. 3. Work piece guiding system

The guiding system is connected to the machine tools gantry and blocks all degrees-of-freedom of the work piece except the one in its feed directory. As a result an own feed drive is not needed. To avoid the gravity caused deflection of the profile in the area of the machine base various additional work piece rests were developed (see Fig. 4). They are mounted on the machine bed located below the moving work piece. Because of the restricted amount of space on the machine bed, the work piece rests have to turn down and up again every time they are ran over by the guidance system.
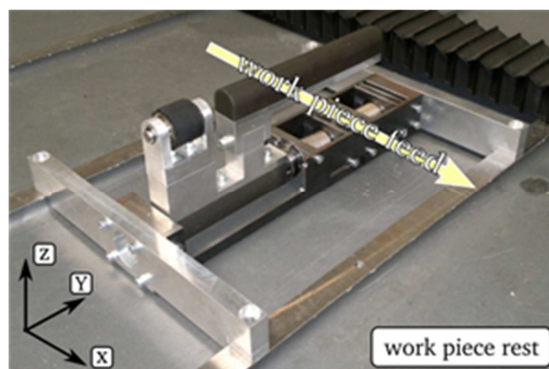

Fig. 4. Work piece rest

The machining of a continuously moving work piece is only possible by the synchronization of the machine tools movements with the work piece feed. The NC program operations have to be superposed by the work piece feed.

The machine tool runs on a *'Bosch Rexroth IndraMotion MTX'* CNC control unit, which provides the special feature *'system axes coupling'*. This function uses a master-slave concept to synchronize the movement of two independent machine tool axes. The work piece motion is captured by a rotary encoder type *'ROD 480'* supplied by the *'DR. JOHANNES HEIDENHAIN GmbH'* and processed as the actual position of an additional axis in the CNC control unit. The generated work piece axis is selected as the master axis, the machine tools x-axis as the slave axis. The system axis coupling can be executed in velocity compensation coupling mode or position correction coupling mode. The machine tool/work piece coupling in velocity compensation mode has been successfully implemented in earlier research work [4]. Between the individual machining operations the coupling has to be deactivated in order to not exceed the machine tools axes ranges. Hence it is not possible to ensure the exact positioning of the milling features by using the velocity compensation coupling mode. For this reason the next step was the implementation of the position correction coupling mode. Because of the digital data storage, the actual position value of the work piece axis is restricted. Hence the axis is selected as a "modulo axis". The modulo value represents the maximum positioning area of this axis. Exceeding that maximum axis position causes an automatically zeroing of the axis actual position.

Figure 5 shows the side-view of the gantry machine tool and the metal profile work piece on it. The work piece feed direction is equivalent to the machine tools x-axis. The rotary encoder is located on the left. Due to the selection as a modulo axis the work piece axis is divided into equidistant segments. The machine gantry (slave) and the work piece axis (master) are coupled in position correction coupling mode. Therefore the command value of the machine tools x-axis is superposed by the actual position of the work piece axis. The system axis coupling feature owns an interpolator, which increases the slave axis velocity till reaching position synchronicity.
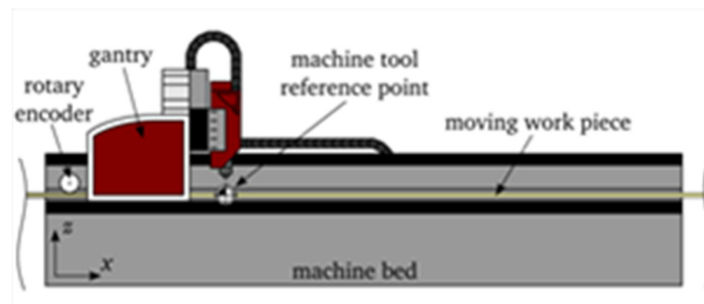

Fig. 5. Side of the machine tool

The activation of the system axis coupling replaces the NC program reference point p_{abs}, which is equal to machine tools reference point, by the synchronization reference point p_{rel}, which is located on the moving work piece (see Fig. 6). Within the modulo area the distance between p_{abs} and p_{rel} represents the actual position of the work piece axis. All positioning commands of the NC program are referenced to p_{rel} during active coupling. After the successful machining of the desired milling feature the coupling is terminated and p_{abs} becomes reference again. The gantry is set back to its initial position and the machining process starts over again. Thus the modulo value sets the distance between the milling

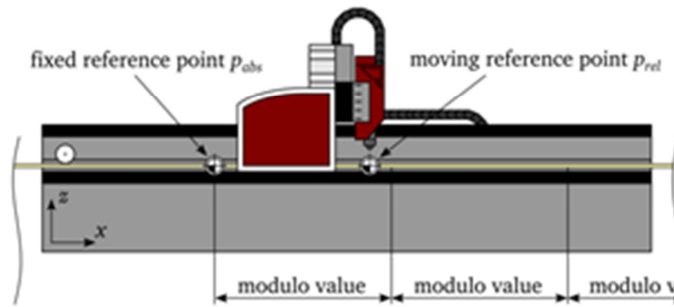features and represents the reference for the position coupling mode.

Fig. 6. Relevant reference points for coupled mode

To illustrate the machining process in coupled mode, Fig. 7 and Fig. 8 show a square milling operation with an edge length of 30mm in the machine tools x-y layer (Fig. 8 on top right). Figure 7 shows the actual position and the contouring error of the x-axis without axis coupling.
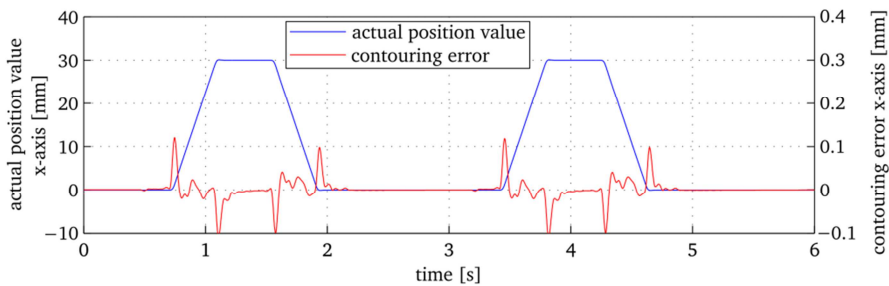

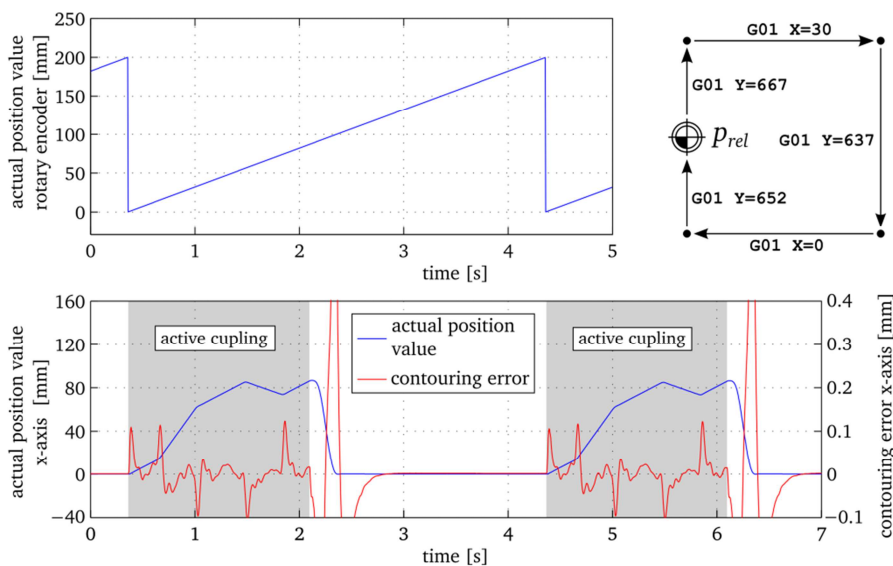Fig. 7. Actual position and contouring error of the x-axis in uncoupled mode

Fig. 8. Actual position of the additionally machine axis (top left); machined geometry (top right); actual position and contouring error of the x-axis in uncoupled mode (bottom)

Figure 8 on top left shows the actual position of the work piece axis in position coupling mode. After reaching the modulo value of 200mm its actual position is zeroed, which initializes the coupling of the machine gantry and work piece axes. Figure 8 on the bottom shows the actual position and contouring error of the x-axis in position correction coupling mode. With the successful synchronization the NC program starts a movement in the machine tools y-axis. Simultaneously the machine tools x-axis is moved synchronously to the work piece axis.

Fig. 9. Work piece machined in coupled mode

After reaching the destination in the y-axis the NC program starts a movement of 30mm in machine tools positive x-axis. This movement and the work piece movement are superposed. The machine gantry runs at a higher speed than the work piece. During the following movement in the machine tools y-axis, the gantry and the work piece are moving synchronously again. After further movements in the machine tools negative x-axis and positive y-axis the milling process ends by reaching the initial point p_{rel}. The axes coupling is terminated and the machine gantry is set back to its initial point p_{abs}. A comparison of the contouring error during coupled and uncoupled milling operation shows no negative influence of the axes coupling on the contouring error and with that on the machining accuracy. The strong rising after canceling the axes coupling results out of the rapid feed´s acceleration. The high contouring error has no influence on machining quality because at this time there is no contact between milling tool and work piece anymore.

3. DISCUSSION OF RESULTS

Figure 9 shows a work piece machined in coupled mode. The work pieces velocity has been 5m/min. With that demonstrator the "milling on the fly" was proofed successfully. Nevertheless the milling features exhibits deviations between actual and reference geometry. The research work (see chapter 2) shows no influence of the axes coupling on the machine tools contouring error. The influence of the milling process forces on the contouring error in coupled and uncoupled machining operation has to be examined. In addition to the machining process forces there are further perturbations affecting the milling process (see Fig. 10). During the test machining operations at times vibrations of the machine tools gantry in its feed direction occurred. Investigations showed vibrations at a frequency of 50Hz superposed to the velocity of the work piece, which arise out of the upstream and downstream forming rack drives. These vibrations are captured by the rotary encoder. In coupled machining mode not only the work piece motion but also the vibrations

are superposed to the gantry motion and with that to the material guiding system. As a result the guiding system induces the vibrations back to the work piece again. The whole system gets unstable. The vibration magnitude is only limited by the gantry drives performance. After all, the vibrations arising out of the forming rack drives, which are superposed to the work pieces motion, are enhanced by the axes coupled machining mode. During the machining process the milling tool additionally affects the work piece as a vibration excitation.

4. SUMMARY

The paper describes the successful implementation of the "milling on the fly" process into a continuous flow production line. For this purpose the actual work piece feed is captured by a rotary encoder. Its feed is processed as the actual position of an additionally machine tool axis by the numeric control. By using the NCs axes coupling feature the motion of the machine tools gantry is coupled with the work pieces motion. The work piece is guided by a specially developed guiding system to handle the milling process forces in the machining area.

During the test machining operations instabilities and malfunctions occurred. They result out of vibration excitation caused by the forming rack drives. Due to the low stiffness of the elongated work piece the excitation causes a huge vibration magnitude.

In the next step it is necessary to investigate the dominant interferences. With that specific knowledge it is possible to take measures to stabilize the machining process and to increase the machining quality. Currently the work piece is guided in the machining area when machined. Nevertheless a proper fixation of the work piece is not possible due to its constant feed.
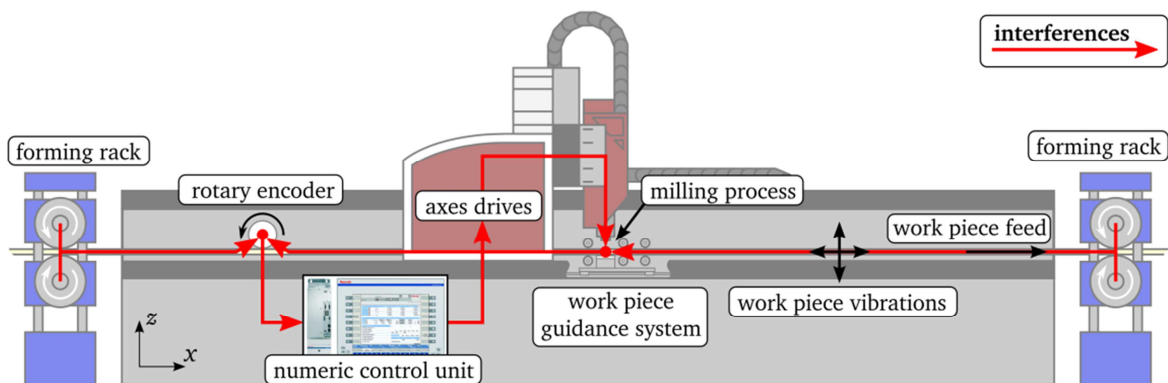

Fig. 10. Perturbations affecting the milling process

The elongated work piece with low stiffness causes a vulnerability to huge vibration magnitudes, which results in a bad machining quality. Therefore a moveable clamping system will be developed, which has several advantages compared to the gantry connected guiding system. The reduced mass of the machine tools gantry enables an increased

dynamic of its x-axis. Because of the avoidance of the relative movement between the guiding systems rolls and the work piece there is no additional vibration excitation. The work piece clamping instead of guiding provides the needed fixation in the machining area. The influence of the poor stiffness of the work piece in the machining area is eased. Alike the machine tool gantry's drives the additional axis will be set up with linear direct drives to provide the required acceleration and velocity. To decrease the influence of the superposed work piece velocity vibrations the input of the rotary encoder will be filtered. Thereby the transfer of the superposed vibrations to the machine tools gantry will be minimized.

ACKNOWLEDGMENTS

REFERENCES

[1]   GÖRTAN O., VUCIC D., GROCHE P., LIVATYALI H., 2009, *Roll forming of branched profiles,* Journal of Materials Processing Technology, 209, 5837–5844.

[2]   ABELE E., JALIZI B., BAKLOUTI F., SCHIFFLER A., 2011, *Herstellung multifunktionaler Strukturen – Mittels Integration des Zerspanprozesses in Walzprofilieranlagen.* Zeitschrift für wirtschaftlichen Fabrikbetrieb (ZWF), Carl Hanser Verlag, München, 106, 522–526.

[3]   ABELE E., JALIZI B., BAYERER A., 2012, *HSC Fräsen in einer kontinuierlichen Fließfertigung - Aufbau eines Werkstückspannsystems zur Positionierung kontinuierlich bewegter Blechprofile*, wt Werkstattstechnik online, Springer-VDI-Verlag GmbH & Co. KG, Düsseldorf, Jahrgang 102, H. 9.

[4]   ABELE E., BOHN A., JALIZI B., HAYDN M., LOMMATZSCH N., COUTANDIN P., 2012, *Steigerung der Prozessqualität einer fliegenden HSC-Fräsmaschine - Maßnahmen zur Qualitätssicherung von Blechprofilen in einer Fließfertigungsstraße*, wt Werkstattstechnik online, Springer-VDI-Verlag GmbH & Co. KG, Düsseldorf, Jahrgang 102, H. 1/2, 27–33.