Optimized Kinematics of Mechanical Presses with Noncircular Gears

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Abstract

The quality of parts manufactured using metal forming operations depends to a large degree on the kinematics of the press ram. Non-circular gears with a rotational-angle-dependent speed ratio in the press drive mechanism offer a new way to obtain those stroke-time behaviours we aim at as an optimum for the various metal forming operations in terms of manufacturing. The paper explains the principle using a prototype press which was built by the Institute for Metal Forming and Metal Forming Machine Tools at Hanover University. It will present the kinematics as well as the forces and torques that occur in the prototype. Furthermore, the paper demonstrates using one example of deep drawing and one of forging that the press drive mechanism with non-circular gears may be used advantageously for virtually all metal forming operations.

Keywords: Press, Gear, Kinematics

1 Introduction

Increasing demands on quality in all areas of manufacturing engineering, in sheet metal forming as well as in forging, go hand in hand with the necessity to make production economical. Increasing market orientation requires that both technological and economic requirements be met. The improvement of quality, productivity and output by means of innovative solutions is one of the keys to maintaining and extending one's market position.

In the production of parts by metal forming, we need to distinguish between the period required for the actual forming process and the times needed to handle the part. With some forming processes we have to add time for necessary additional work such as cooling or lubrication of the dies. This yields two methods of optimization, according to the two aspects of quality and output. In order to satisfy both aspects, the task is to design the kinematics taking into account the requirements of the process during forming; also to be considered is the time required for changing the part as well as for auxiliary operations in line with the priority of a short cycle time.

2 Pressing Machine Requirements

One manufacturing cycle, which corresponds to one stroke of the press goes through three stages: loading, forming and removing the part. Instead of the loading and removal stages we often find feeding the sheet, especially in sheer cutting. For this, the press ram must have a minimum height for a certain time. During the forming period the ram should have a particular velocity curve, which will be gone into below. The transitions between the periods should take place as quickly as possible to ensure short cycle time.

The requirement of a short cycle time is for business reasons, to ensure low parts costs via high output. For this reason stroke numbers of about 24/min for the deep drawing of large automotive body sheets and 1200/min for automatic punching machines are standard practice. Increasing the number of strokes in order to reduce cycle times without design changes to the pressing machine results in increasing strain rates, however. This has a clear effect on the forming process, which makes it necessary to consider the parameters which determine the process and are effected by it.

In deep drawing operations, the velocity of impact when striking the sheet should be as low as possible to avoid the impact. On the one hand, velocity during forming must be sufficient for lubrication. On the other hand, we have to consider the rise in the yield stress corresponding to an increase in the strain rate which creates greater forces and which may cause fractures at the transition from the punch radius to the side wall of the part.

In forging, short pressure dwell time is desirable. As the pressure dwell time drops the die surface temperature goes down and as a result the thermal wear. This is counteracted by the enhanced mechanical wear due to the greater forming force, but the increase due to the strain rate is compensated by lower yield stress because of the lower cooling of the part. The optimal short pressure dwell can nowadays be determined quantitatively using the finite element method [3]. In addition to cost avoidance due to reduction in wear, short pressure dwell time is also an important technological requirement for the precision forging of near net shape parts, which has a promising future.

The requirements of high part quality and high output will only be met by a machine technology which takes into account the demands of the metal forming process in equal measure to the goal of decreasing work production costs. Previous press designs have not simultaneously met these technological and economical requirements to a sufficient extent, or they are very costly to design and manufacture, such as presses with link drives [6]. This makes it necessary to look for innovative solutions for the design of the press. Its design should be largely standardized and modularized in order to reduce costs [6].

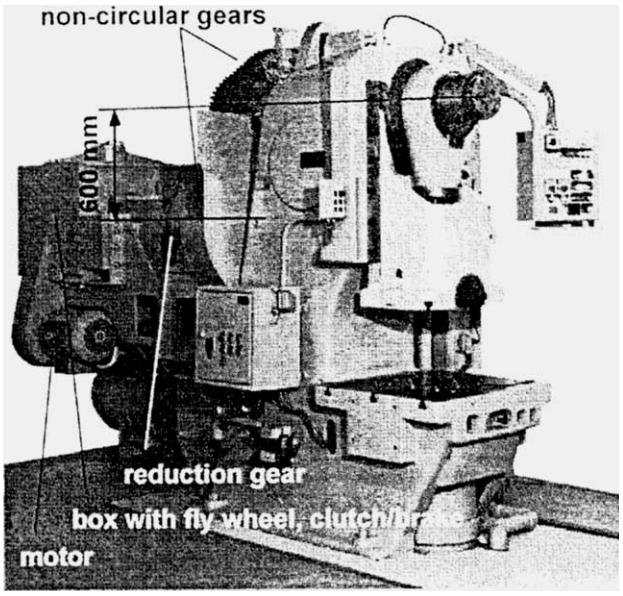

Fig 1: Prototype press.

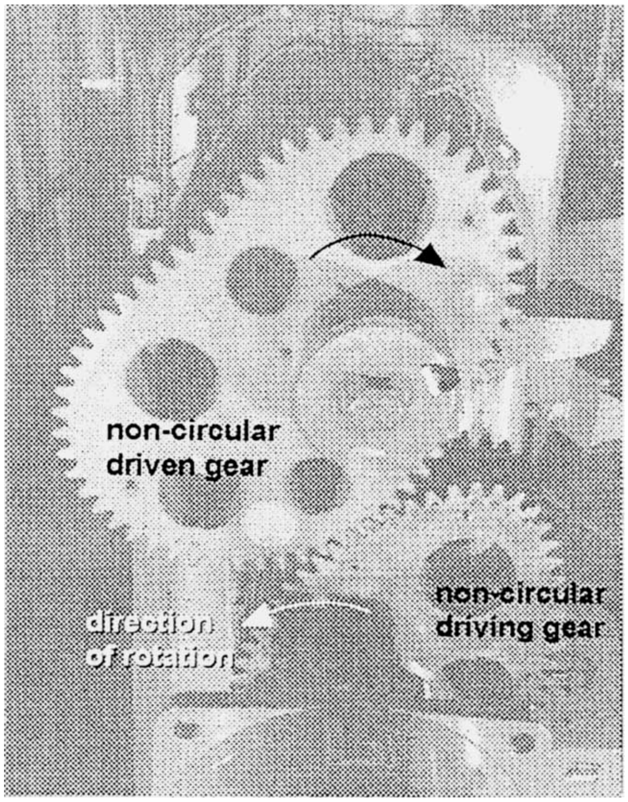

Fig. 2 View of the gears from the rear.

3 Press Drive with Non-circular Gears

3.1 Principle

The use of non-circular gears in the drive of mechanical crank presses offers a new way of meeting the technological and economic demands on the kinematics of the press ram. A pair of non-circular gears with a constant center distance is thus powered by the electric motor, or by the fly wheel, and drives the crank mechanism itself. The uniform drive speed is transmitted cyclically and non-uniformly to the eccentric shaft by the pair of non-circular gears. If the non-circular gear wheels are suitably designed, the non-uniform drive of the driven gear leads to the desired stroke-time behaviour of the ram. Investigations at the Institute for Metal Forming and Metal Forming Machine Tools (IFUM) of Hanover University have shown that in this simple manner all the relevant uninterrupted motions of the ram can be achieved for various forming processes [2].

Apart from the advantages of the new drive, which result from the kinematics and the shortened cycle time, the drive concept is distinguished by the following favourable properities. Because it is a mechanical press, high reliability and low maintenance may be expected. In comparision to linkage presses the number of parts and bearings is clearly reduced. Above all, a basic press type can be varied without further design changes by installing different pairs of gears, designed according to the demands of the customer. Unlike link drives, bearing locations and installations do not change within one load class as a result of different kinematics. Thus the above mentioned requirement of modularization and standardization is taken into account. Reductions in time and costs are possible for the design and press manufacture.

3.2 Prototype

At the Institute for Metal Forming and Metal Forming Machine Tools (IFUM) a C-frame press has been remodelled and a pair of non-circular gears was installed. The previous backgears were replaced by a planetary gear set for this purpose. The work carried out shows that remodelling of existing presses for the new drive is possible. The state of the press at the end of the remodelling is shown in figure 1. The press is designed for a nominal ram force of 1,000 kN and 200 kN of the die cushion. The center distance of the non-circular gears is 600 mm. The pair of non-circular gears has an average transmission ratio of 1. Each gear wheel has 59 gear teeth, straight-toothed, module 10 mm (figure 2). The face width is 150 mm. The gears have involute gear teeth. We assume a non-circular base curve for the design of the flank geometry. As a result the tooth geometry of a non-circular gear varies along the circumference. In spite of this, it can be derived from the well-known trapezium rack, however [4, 5]. An algorithm for the computation, which takes the addendum and dedendum into account exactly, has been developed.

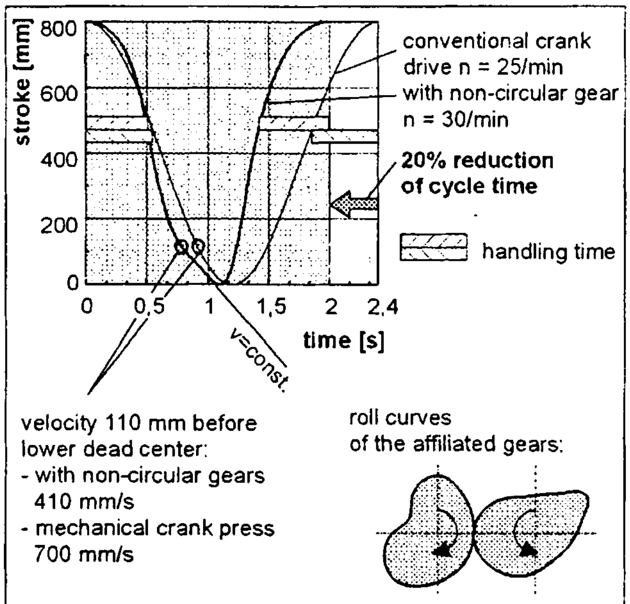

Fig. 3: Kinematics of the prototype press.

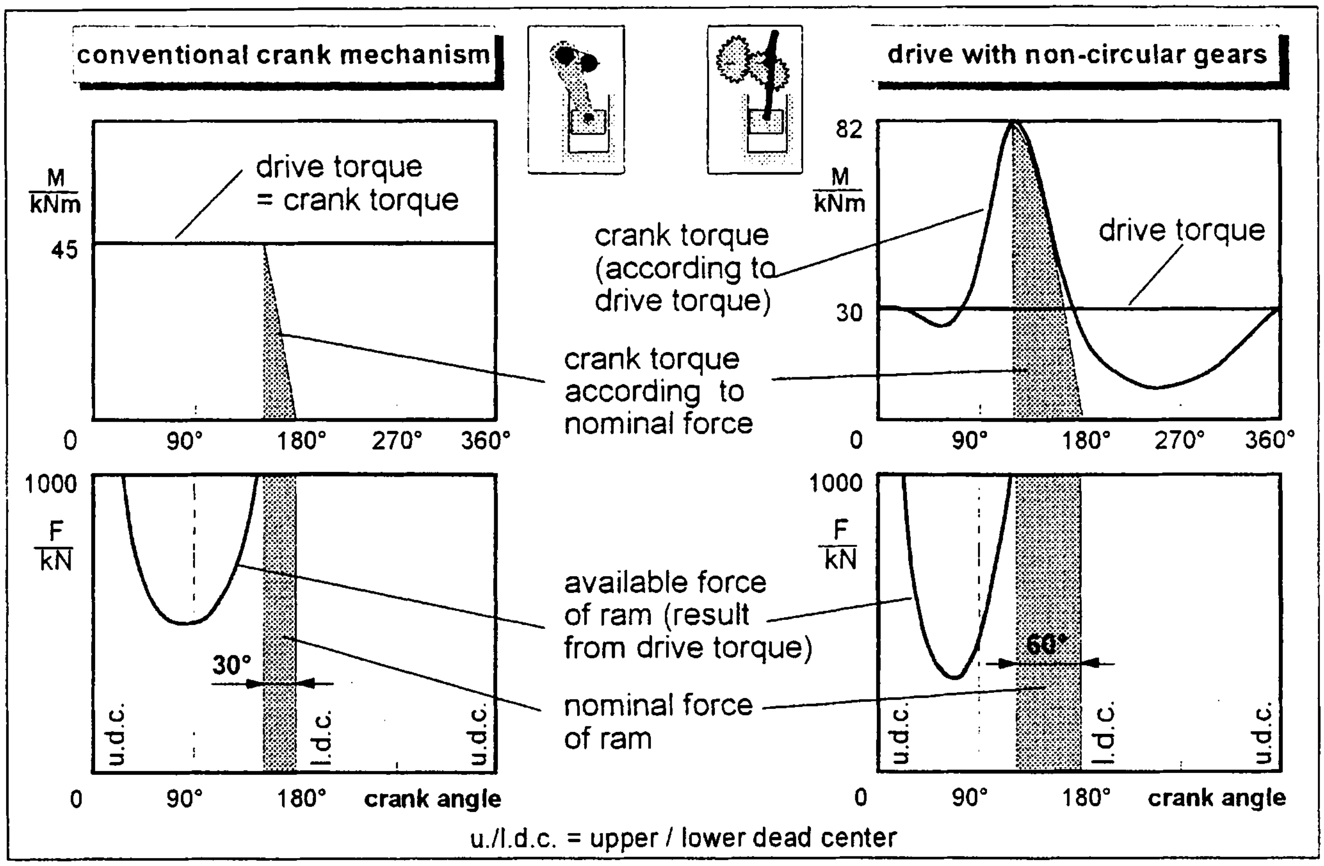

Fig. 4: Forces and torques of the prototype press, compared with conventional mechanical crank press.

The press is designed for deep drawing of flat parts in single stroke operation mode. The maximum ram stroke is 180 mm, the number of strokes 32/min. At a stroke of 140 mm the ram velocity almost remains constant 71 mm/s from 60 mm before lower dead center until lower dead center, see figure 3. Thus the velocity corresponds to the working velocity of hydraulic presses. The velocity of incidence of a crank mechanism with the same number of strokes would be 220 mm/s, in comparison. In order to keep the same average velocity with a crank press, the number of strokes would have to be halved. The short cycle time of the remodelled machine results from the fast upward motion. Because the press is run in single stroke operation mode, no particular requirements were made concerning handling time during design.

The drive mechanism of the prototype with non-circular gears has in addition a favourable effect on the ram forces and the driving torques (figure 4). For a crank press the nominal force is normally available at 30° rotation of the crank shaft before the lower dead center. This corresponds to a section under nominal force of only 7.5% relative to the stroke. To reach the nominal force of 1,000 kN, the drive has to supply a torque of 45 kNm at the crank shaft. The prototype only requires 30 kNm on account of the additional transmission of the non-circular gears. They are transmitted to a cyclic, non-uniform crank shaft torque, resulting in a nominal force range from 60° to the lower dead center. This corresponds to 27.5% of the stroke. We always find similar conditions if the pair of non-circular gears is stepped down in the operating range of the press. This will almost always be the case with sheet metal forming and stamping. It is thus possible to design some machine parts in a weaker form and to save costs this way.

4 Further Design Examples

Using the examples of two stroke-time behaviours the design is illustrated in the following. A range of parts is assumed which are to be manufactured by the press. For this purpose the ram velocity requirements and the forming section of the assumed stroke need to be quantified. Furthermore, the time needed for the handling of the part needs to be determined, and also the minimum height which the ram has to assume during the handling. From this, we design the sequence of movements, and we describe it mathematically. At the IFUM, a software program developed by the institute is used. From this mathematical description of the stroke-time behaviour we can calculate the speed ratio of the non-circular gears needed. From this we obtain the rollcurves of the gears [1, 2, 7].

In a first example the ram velocity in deep drawing is supposed to be constant during the sheet metal forming at least over 100 mm before the lower dead center and it is supposed to be about 400 mm/s. Let the number of strokes be fixed at 30/min. Above 450 mm section of stroke, let the time for the handling of the part be the same as for a comparable crank press with 25 strokes per minute. Figure 5 shows the stroke-time behaviour , which is attained by the sketched pair of gears. The gear wheels are represented by their rollcurves. The conventional cosine curve at 25/min is given for comparison. In addition to the reduction of cycle time by 20%, the ram velocity of impact onto the sheet is also considerably reduced. 110 mm before the lower dead center, the velocity of impact is 700 mm/s when using the crank mechanism and only 410 mm/s when operated with non-circular gears.

A second example shows a drive mechanism as is used for forging. In figure 6, stroke-time behaviour of a conven-

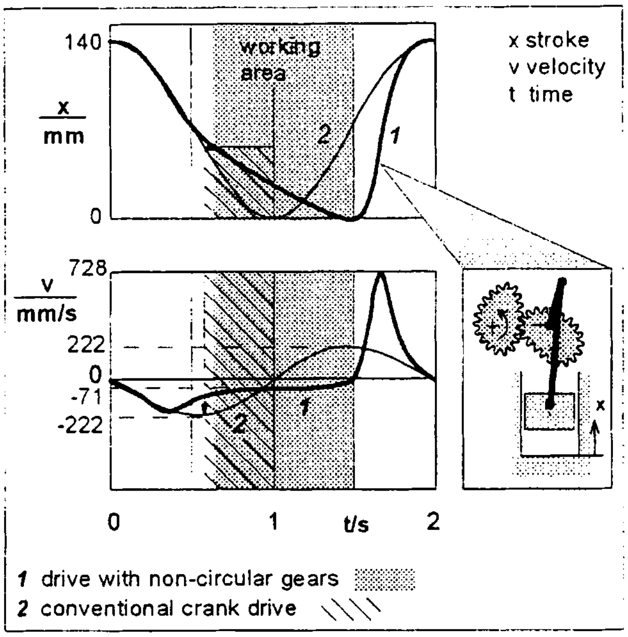

Fig. 5: Design for deep drawing.

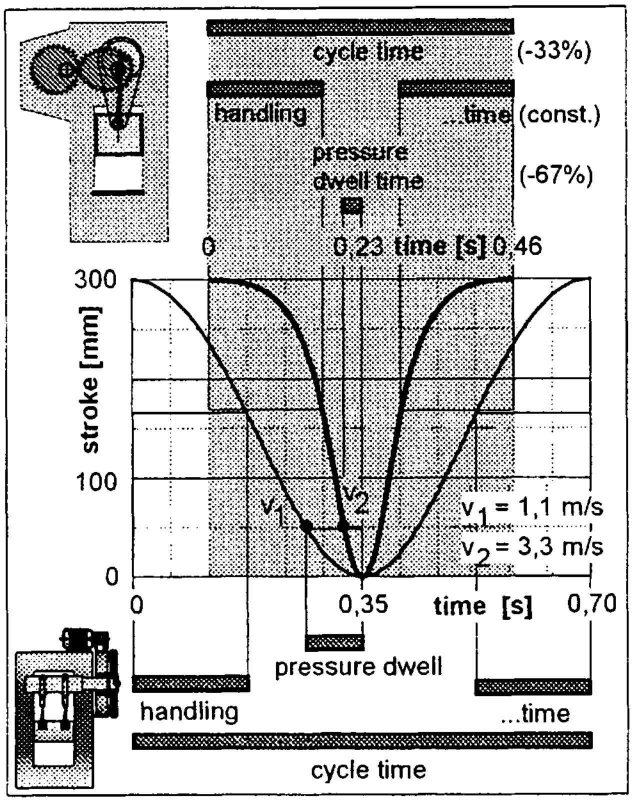

Fig. 6: Design for forging.

tional forging crank press is compared with the kinematics of the press with non-circular gears illustrated in the picture. The cycle time of the crank press is 0.7 s, the number of strokes is 85/min and the nominal force is 20 MN. Its pressure dwell time is 86 ms with a forming section of 50 mm. The pressure dwell of the press depicted with non-circular gears decreases by 67% to 28 ms. It thus reaches the magnitude familiar from hammers. By increasing the number of strokes by a factor of 1.5, the cycle time decreases by 33% to 46 ms. In spite of this, the handling time remains the same compared to conventional crank press on account of the kinematics of the non-circular gears. In order to achieve these kinematics in this case, a conventional circular gear may be used as driving gear, arranged eccentrically. This reduces the costs for gear manufacture.

These examples show that different kinematics can be achieved by using non-circular gears in press drives. At the same time the potential of this drive with respect to the realization of the desired kinematics becomes clear as does the reduction of cycle times in production. By varying the examples it is also possible to increase the velocity after impact in deep drawing operations if this sequence of motions is advantageous for the range of parts to be produced on the press, for reasons of lubrication, for example.

5 Conclusions

The requirements of high productivity, reduced costs and the guarantee of high product quality to which all manufacturing companies are exposed, applies particularly to companies in the field of metal working. This situation leads us to reconsider the press drive mechanism in use up to now.

The new drive for crank presses with non-circular gears described here allows us to optimize the kinematics of simple mechanical presses. This means that the cycle time is shortened to achieve high productivity and the kinematics follows the requirements of the forming process. The design effort needed is low. In contrast to presses with link drives, other kinematics can be achieved during the construction of the press by using other gears without changing bearing locations. This allows the modularization and standardization of presses.

6 Acknowledgement

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7 References

[1] Bernard, J., 1992, Optimization of Mechanism Timing Using Noncircular Gearing, Mechanical Design and Synthesis, Vol. 46, p. 565-570.

[2] Doege, E., Hindersmann, M., 1996, Fertigungsgerechte Kurbelpressenkinematik durch Unrundzahnräder. VDI-Z Special Antriebstechnik I/96, p. 74-77.

[3] Doege, E., Nägele, H., 1994, FE-Simulation of the Precision Forging Process of Bevel Gears, Annals of the CIRP, Vol. 43, p. 241-244.

[4] Hindersmann, M., Betke, V., 1996, Unrunde Zahnräder – ein wiederentdecktes Maschinenelement, Konstruktion, Vol. 48, p. 256-262.

[5] Litvin, F. L.: 1994, Gear geometry and applied theory, PTR Prentice Hall, Englewood Cliffs (NJ, U.S.A.).

[6] Niemitz, D., 1992, Anforderungen an Großraumstufenpressen; Pflichtenheft für die Auftragsvergabe. In: Blechbearbeitung '92, Int. Congress 27.-28.Oct.1992, VDI-Bericht, Vol. 946, p.231-253.

[7] Ogawa, K., Yokoyama, Y., Koshiba, T., 1973, Studies on the Noncircular Planetary Gear Mechanisms with Nonuniform Motion, Bulletin of the JSME, Vol. 16, p. 1433-1442.