Unique Capabilities and Results of Research & Development in the Areas of Cross-roll Piercing & Assel Elongating

by

Gerlach, Frank; Rudatus, Detlef
Verein zur Förderung der Umform- und Produktionstechnik Riesa e. V.
Rittergutsstr. 6, 01591 Riesa, Germany

Summary

VFUP, a society for promoting forming and production technology, was founded as a non-profit industrial research organization in 1993. The main objective of **VFUP** has been, & continues to be, research and development aimed at understanding & advancing the state of the art of the cross-roll piercing and Assel rolling processes used in the manufacture of steel and non-ferrous seamless tubes. The work is carried out utilizing a unique, modern Universal cross-rolling mill that permits testing under production conditions.

This paper describes some of the sophisticated examinations that have been undertaken in order to understand and improve complex tube forming processes and the forming equipment. Cross-roll piercing studies have compared two- and three-roll piercing & various guide arrangements (linear guides, guide rollers, Diescher type discs) and with normal & driven mandrels. Special steel grades & tooling have also been tested. Assel elongation trials have been conducted with two- and three rolls and various mandrel arrangements (free-floating, retained, controlled-movement, driven).

Sophisticated, real-time measurement of roll forces, roll torques, power consumption, mandrel forces, pusher forces, forces on guides, forces & torques on Diescher type discs have been made in all of the above-mentioned trials in order to optimise each process with regard to energy consumption, tool wear, and product quality. Unique, wireless roll force and roll torque measurement systems have been developed.

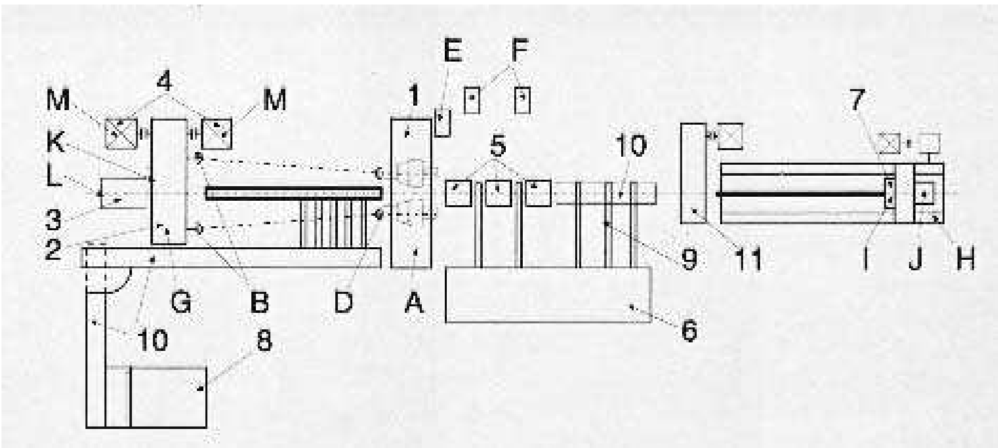
1 Technical test conditions

1.1 Equipment

Making and processing of seamless tubes by cross-rolling and Assel rolling require consolidated and experimentally found knowledge to determine and optimize technical, technological and material-specific parameters and deformation and process parameters as well.

By installing a universal test cross-rolling mill at the test area of the former Ingenieurschule für Walzwerk- und Hüttentechnik in Riesa in 1991 the possibilities for carrying out practical and production-like deformation trials have been realized.

Figure 1 shows the layout of the test mill mentioned above and the most important machinery and the arrangement of measuring devices used.



equipment		arrangement of measuring points	
1	- mill	A	- roll forces
2	- main drive gear	B	- torques of driven spindles
3	- hydraulic pusher	C	- furnace temperature
4	- main drive 1 and 2	D	- initial temperature
5	- centering units	E	- exit temperature
6	- cooling basin	F	- exit speed
7	- mandrel bar carriage	G	- rpm of rolls
8	- electrically heated furnace	H	- mandrel speed
9	- ejector	I	- rpm of mandrel
10	- roller table	J	- mandrel force
11	- special drive unit of mandrel bar	K	- pusher force
		L	- pusher speed
		M	- armature voltage and current of main drives

Figure 1: Layout of cross-rolling mill and arrangement of measuring devices

This rolling mill is capable of deforming round solid billets, hollows and tubes.

Figure 2 is a survey showing the process variances of test mill.

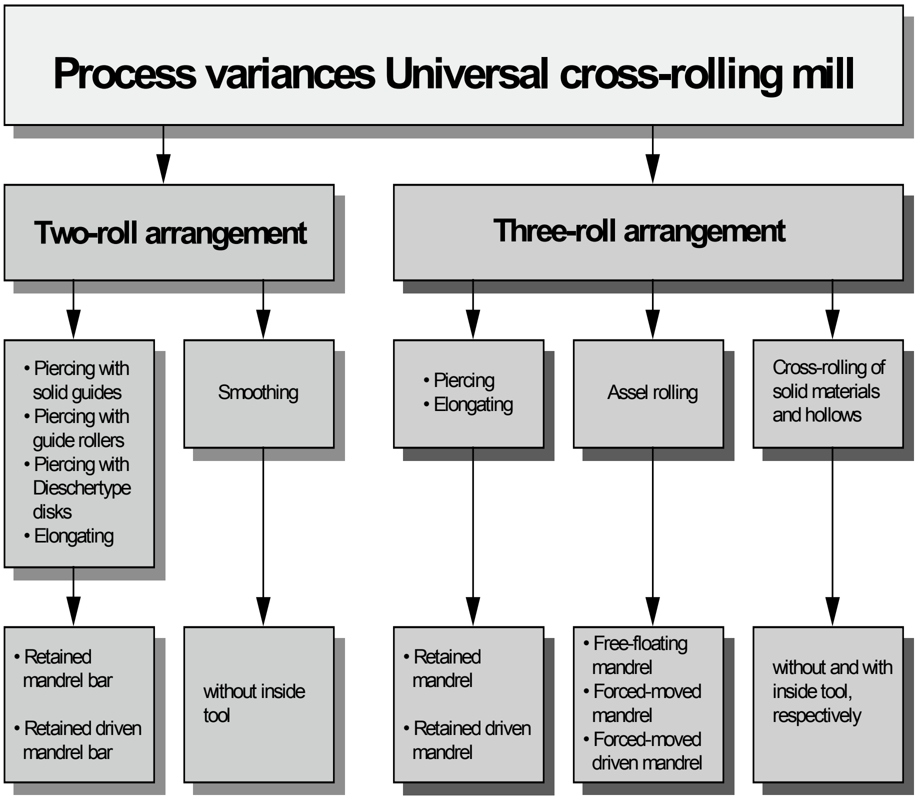


Figure 2: Process variances Universal cross-rolling mill

Figures 3 and 4 show possible roll arrangements.

For carrying out deformation tests it is possible to vary some of the process parameters within certain limits.

The test mill is driven by two dc motors each having a capacity of 280 kW through a gear box the transmission ratio of which is i = 5.

The test mill is modular in and equipped with a device for electrical setting of feed angle, which is driven by a three-phase current motor having a capacity of 23 kW and rotating with a speed of 725 min^{-1} through a gear box, and with a device for roll setting, which is driven by a three-phase current motor having a capacity of 2.2 kW and rotating with a speed of 1395 min^{-1}.

The mandrel bar carriage is driven by a dc motor having a capacity of 27 kW and rotating with a speed of 725 min^{-1} and can be moved over a maximum distance of 3750 mm at a speed of up to 1,04 m/s.

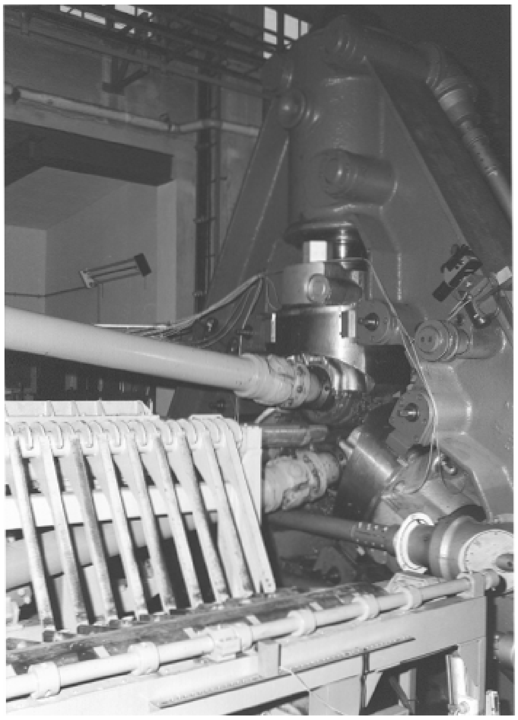


Figure 3: Three-roll arrangement for piercing and elongation, entry side

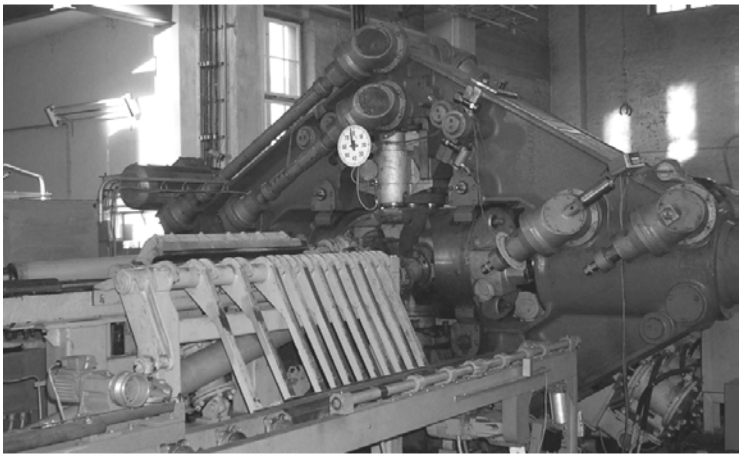


Figure 4: Two-roll arrangement with guide shoes, entry side

Rolling stock heated up to rolling temperature in a furnace which is electrically heated by using silit rods is moved to a pushing tray via a roller table, a pivotable section and a transfer device. From there it is pushed into the roll gap by using a hydraulically operated pusher.

Three centering units, a transfer device, a mandrel bar carriage, and a device for cooling the rolled material are arranged at the exit side of mill (see **figures 5 and 6**).
A central control panel is used for setting and operating of mill.

The most important technical data of test mill are summarized in **table 1**.

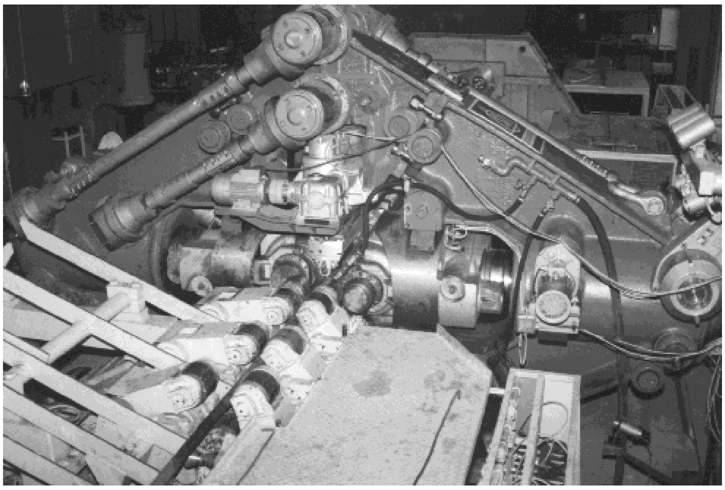


Figure 5: Two-roll arrangement with centring units at the exit side

Figure 6: Two-roll arrangement with device for transferring of shells at the exit side

Table 1: Technical data of Universal cross-rolling mill

Parameter	Dimension
roll diameter	340 ... 420 mm
body length	350 mm
feed angle, two-roll arrangement three-roll arrangement	0 ... 17 degrees 0 ... 15 degrees
angle of conic, divergent or convergent two-roll arrangement three-roll arrangement	 0 ... 5 degrees 0 ... 7,5 degrees
drive power of dc motors	2 x 280 kW
roll force	max. 650 kN per roll
roll torque	max. 45 kNm per spindle
rotational speed of rolls	72 ... 225 rpm
length of initial material	550 ... 1000 mm
diameter of initial material	2700 mm
rolled length, max.	70 ... 133 mm

1.2 Measuring devices of test mill

The following important parameters of deformation process can be measured and evaluated:

❑ **Mechanical parameters**

- Support forces and torques of each roll which are used to calculate total deformation force and torque
- Support forces of guide elements
- Mandrel force, mandrel tip force, rotational speed and speed of mandrel bar carriage
- Force, distance and speed of pusher

- Torque and speed of Diescher-type disks
- Roll speed and exit speed of rolled material

- **Electric parameters**
  - Armature current and armature voltage of motors used for driving rolls and Diescher-type disks

- **Thermal parameters**
  - Temperature of furnace chamber and discharging temperature
  - Temperature of rolling stock before and after rolling

Further parameters such as mentioned below are measured and evaluated, respectively.

- **Geometry of rolling stock**
  - Diameter, length and wall before and after deformation to determine geometric deformation parameters

- **Visual sizes**
  - Judgement of initial material
  - Judgement of inside and outside surface of rolled stock
  - Judgement of deformation tools

Measured quantities and measuring methods used with carrying out trials with two-roll and three-roll arrangements are summarized in **table 2**.

Measured quantities are processed by using analogue and digital measuring amplifiers and detected, stored and processed by personal computers.

Table 2: Survey of measured quantities and measuring methods used at the universal cross-rolling mill

Measured quantity	**Kind of cross-rolling**		**Measuring devices and measuring procedure, resp., and principle of measurement**
	Two-roll piercing Using guides	**Three-roll piercing/ elongation**	
1	**2**	**3**	**4**
mechanicaly quantities:			
forces of working rolls	x	x	measurement based on wire strain gauge (force gauge)
torques of driving spindles	x	x	measurement based on wire strain gauge (measuring hub)
rpm of working rolls	x	x	incremental shaft encoder
rpm of plug / mandrel	x	x	incremental shaft encoder
mandrel bar speed	-	x	incremental shaft encoder
rpm of Diescher-type disks	x	-	tachometer generator/analogue
forces of Diescher-type disks	x	-	measurement based on wire strain gauge (force gauge)
force of top guide roll	x	-	measurement based on wire strain gauge (force gauge)
force of bottom guide roll	x	-	measurement based on wire strain gauge (force gauge)
force of top guide shoe	x	x	measurement based on wire strain gauge (force gauge)
force of bottom guide shoe	x	x	measurement based on wire strain gauge (force gauge)
mandrel force			measurement based on wire strain gauge (force gauge)
mandrel tip force	x	x	measurement based on wire strain gauge (force gauge)
pusher force			measurement based on wire strain gauge (force gauge)
pusher speed	x	x	incremental shaft encoder
temperatures:			
furnace temperature	x	x	thermocouple
initial temperature T1	x	x	infrared pyrometer
exit temperature T2	x	x	infrared pyrometer
electrical quantities:			
armature voltage of main drives	x	x	analogue
armature current of main drives	x	x	analogue
further quantities:			
exit speed	x	x	measuring optical equipment

1.3 Special features of test mill

In addition to the extensive measuring devices mentioned above, the test mill incorporates the following special features to facilitate carrying out tests.

- **Hydraulic pusher**

A hydraulic pusher generating an axial force of up to 100 kN is used to push the rolling stock into the roll gap. Pushing speed can be varied.

- **Rolling with controlled movement of inside tools**

During rolling, the mandrel bar carriage can be moved axially. It is possible to freely change the speed of carriage up to 1.04 m/s so that Assel rolling tests can also be carried out with a controlled movement of mandrel.

However, mandrel can also be driven. It is possible to use such a forced driving of mandrel with all piercing and elongating processes. In other words, mandrel or Assel bar can be moved with a speed which is higher or lower than that expected to be generated during rolling. It is also possible to move the inside tool in a direction opposite to the rotational direction of hollow. If wanted, rolling with fixed inside tools such as mandrel and Assel bar can be realized. The mandrel is driven by an electric motor having a capacity of 112 kW. Speeds of 460...1380 min^{-1} of this motor are transmitted to the mandrel through a gear box having a transmission ratio of 1:1.

- **Quick changing of feed angle**

An electric motor allows the preset feed angle to be increased quickly during rolling.

- **Measuring of mandrel tip force**

Special mandrels and a correspondingly designed mandrel bar allow to measure the forces applied to the mandrel tip. **Figure 7** shows such a measuring mandrel.

Figure 7: Special mandrel for measuring tip force

- **Application of protective gas**

In order to prevent the hollow space formed during rolling from scaling, it is possible to blow a protective gas into it. For example, such a measure is necessary, if copper is deformed. However, such a technology requires the use of a special mandrel bar and a special kind of connecting mandrel and mandrel bar to each other. This kind of connection can also be used for cooling the mandrel with water.

2 Presentation of selected results of trials

2.1 Cross-roll piercing

Cross-roll piercing trials were carried out with the two-roll arrangement and three-roll arrangement as well.
Rolled and direct cast round billets made of steels and non-ferrous metals as well were used with these trials.

Steel grades used were low-alloyed up to medium-alloyed and high-alloyed steels (such as structural steels, heat-treatment steels, heat-resisting steels, boiler tube steels, stainless and acid-resistant steels, oil-field tube steels).

Non-ferrous metals used with these trials were mainly copper and copper alloys.

The diameter of billets was between 90 and 130 mm and the hollows had diameters of 63 up to 149 mm and walls from 5 to 13 mm.

❑ Cross-roll piercing of copper

VFUP carried out comprehensive examinations concerning cross-roll piercing of copper. The trials were aimed at rolling hollows to make tubes the quality of which is that of copper tubes produced industrially. With these trials, direct cast copper billets were pierced by using the two-roll arrangement and the three-roll arrangement as well and the hollows made in this way were further processed by cold pilger rolling and drawing at industry partners of VFUP. The diameters of direct cast billets were 89 mm and 115 mm, respectively. The hollows made by cross-roll piercing had outside diameters of 90 up to 110 mm and walls of 10 mm.

With these trials, stickers were produced to get comprehensive information concerning the deformation of copper. **Figure 8** shows segments of a sticker rolled with the three-roll arrangement of mill.

Figure 8: Segments of a sticker

Figures 9 and 10 show diagrams of possible valuations of stickers with which important geometric parameters and deformation parameters in the area of deformation zone were determined. Such parameters are the courses of diameter and wall thickness, the courses of elongation and torsion and ovality of rolled material.

Furthermore, logarithmic deformations in axial, tangential and radial directions were determined.

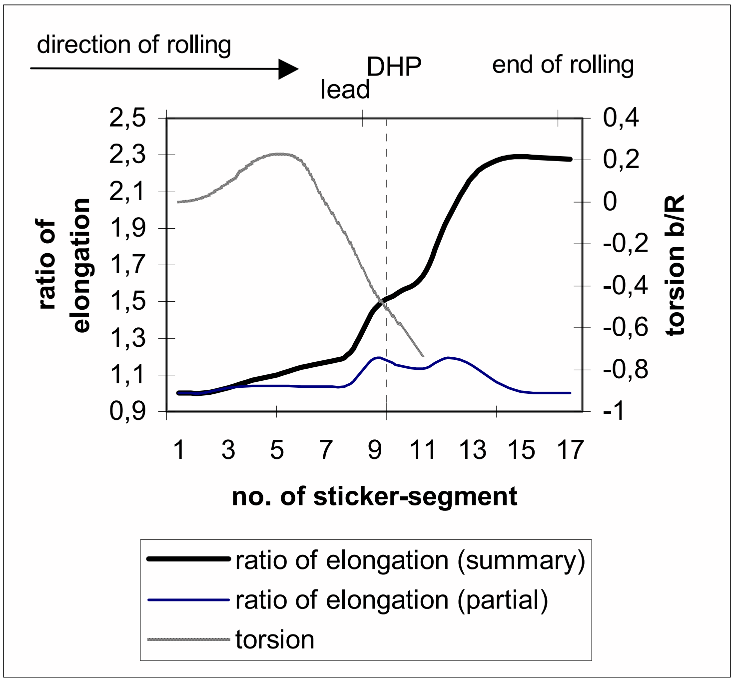


Figure 9: Valuation of a sticker

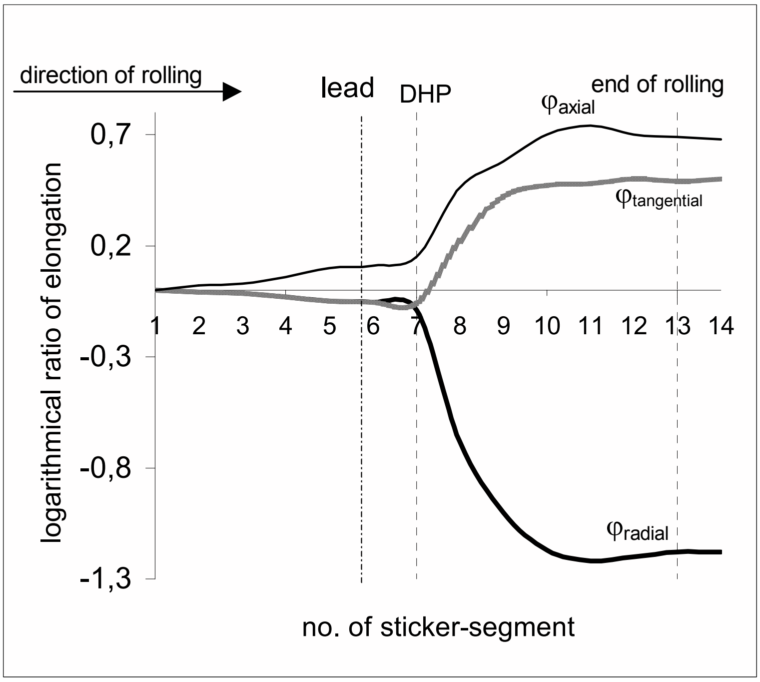


Figure 10: Course of logarithmic deformation determined from a sticker

Within the framework of numerous cross-piercing trials carried out at VFUP, mandrels made of Si_3N_4 ceramics were used for the first time (see **figure 11**).

In spite of great thermal, mechanical and chemical loads, these mandrels did not show any wear.

Figure 11: Mandrel made of ceramics and adapter used with cross-roll piercing of copper

- ❑ **Two-roll cross piercing of steels**

With two-roll piercing using Diescher-type disks and two-roll piercing using guide shoes it was possible to pierce rolled and also direct cast round billets to make hollows having diameter/wall ratios > 14. Maximum diameter/wall ratio gained with these trials was 16.4. Furthermore, excellent surface qualities of hollows were obtained.

Eccentricities of rolled hollows were 1,0 ... 1,7 %. Diameter variations were within the range of 0.1 to 0.3 %.

Figure 12 shows the cross-section of a sticker cut in lengthwise direction
In this figure, the compressed area of inside surface of sticker can clearly be seen.

The compressed area of mandrel which corresponds to that of the inside surface of sticker is shown in **figure 13**.

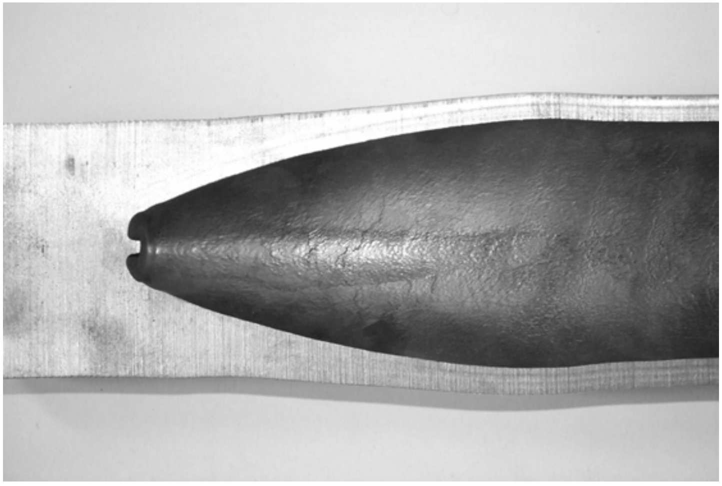


Figure 12: Sticker cut in lengthwise direction

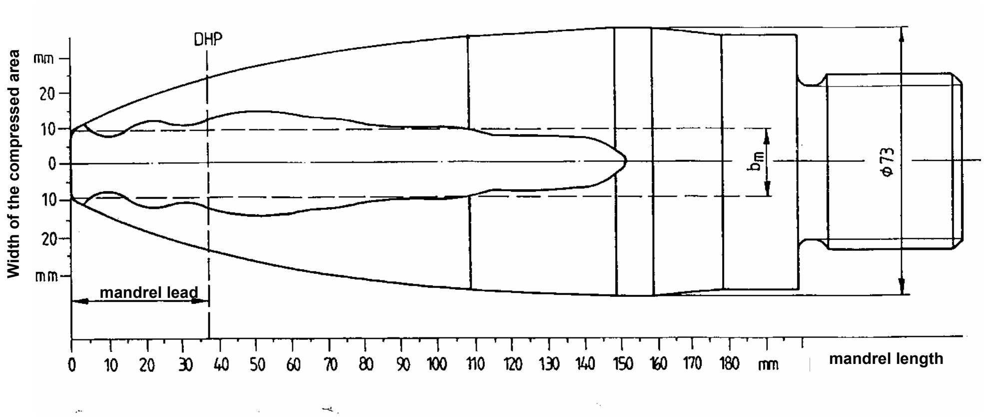


Figure 13: Representation of compressed area of mandrel

❑ Three-roll cross piercing of steels

A characteristic feature and, at the same time, one of the main advantages of three-roll cross piercing is self-guiding and self-centring of rolled stock between the three rolls.

However, three-roll cross piercing shows further advantages if compared with two-roll cross piercing.

With three-roll cross piercing, smaller wall and diameter tolerances and better centricities of hollows and, therefore, remarkably higher precision of product geometry can be expected.

Cross-roll effect (alternating ovality) known from two-roll cross piercing does not occur with three-roll cross piercing and, therefore, there is no danger that internal defects are formed, if non-deformed direct cast round billets or billets made of alloyed steel showing constricted formability are used as initial material.

With three-roll cross piercing, as rolling stock is guided by the rolls but not by guide shoes used with two-roll cross piercing, formation of defects on the outside surface can be prevented.

With comprehensive examinations carried out at VFUP comparable process parameters were determined. These parameters have contributed to extend the knowledge in the field of cross-roll piercing.

VFUP succeeded in piercing direct cast billets to make hollows having diameter/wall ratios > 17.5 and showing excellent inside and outside surfaces. Eccentricities and ovalities of hollows were found to be in the ranges of 1,0 to 2,1 % and 0.1 to 0.3 %, respectively.

2.4 Assel rolling

Comprehensive examinations carried out by VFUP and partly together with some of its partners of industry were mainly aimed at mathematical modelling of Assel rolling process, improving of tube geometry and increasing of yield.

With these trials, hollows made of non-alloyed steel, low-alloyed up to medium-alloyed steel and high-alloyed steels were rolled.

The hollows used with these trials had diameters between 91.5 and 133 mm and walls from 7.2 to 30 mm. The elongated hollows had diameters between 59 and 124 mm and walls from 3.0 to 14.2 mm.

With these trials, the effect of lubricants on Assel rolling of hollows made of steel grades 100Cr6 and 16MnCr5 was also examined.

If lubricants are effectively used with Assel rolling, exit speed can be increased by up to 25 %. Therefore, axial forces of Assel bar decrease correspondingly.

Two kinds of lubricants free of graphite and graphite-containing lubricants each were tested and the results of these trials and those gained with trials without using lubricants were compared to each other.

Figure 14 shows the percentage changes of exit speed, bar force and feed efficiency factor for steel grade 100Cr6.

The lubricants free of graphite are designated by W1 and W2, respectively and the graphite-containing lubricants by S1 and S2, respectively.

However, not only the effect of lubricants on the process kinematics was examined, but a simple method to determine the friction coefficient from the measurement data was also developed.
Any unfavourable lubrication method effects the process kinematics and the quality of shells as well.

Figure 15 shows that section of a shell, where on the inside surface thereof flakes were formed. Such a flake formation is caused by momentary sticking of tool and work-piece with each other, that is by an alternation between sticking and slipping, the so-called stick-slip effect

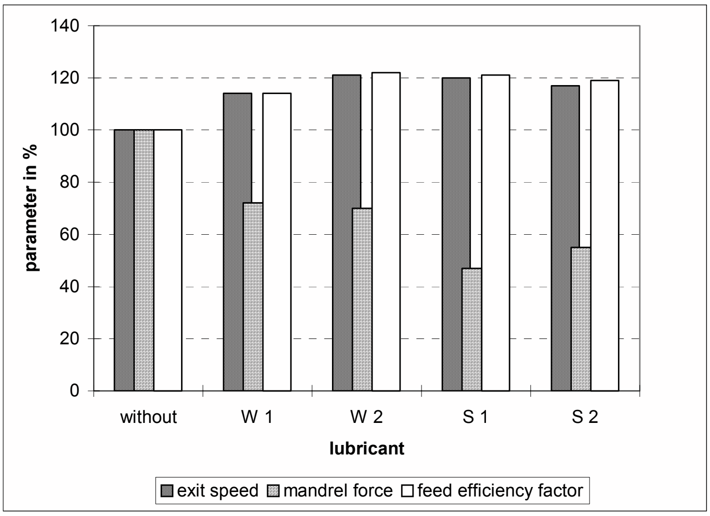


Figure 14: Effect of lubricants on process parameters with Assel rolling of hollows made of steel grade 100Cr6

Figure 15: Flake formation on the inside surface of a shell

Thermomechanical Assel rolling of tubes

Another aspect of developmental work carried out by VFUP is to find out if Assel rolling can be utilized with semicold forming. The work is aimed at obtaining a structure effect by carrying out rolling within a defined temperature range below the A_{c3} transformation temperature and with gaining of a high reference amount of deformation, which ensures favourable properties of shells to be further processed.

2.5 High-reduction rolling of solid billets and hollows

Trials carried out to roll solid billets with gaining high reductions have shown that three-roll cross rolling offers a good alternative for this purpose. With these trials, billets made of unalloyed steels, bearing steels and stainless steels were used. The billets showed dimensional accuracy and straightness required to get good results. With these trials, area reductions of 50 to 80 % were gained.

Figure 16 shows a sticker of a massive-reduced billet

Figure 16. Sicker of a massive-reduced billet

Trials to realize high-reduction Assel rolling of hollows were also carried out. With these trials, area reductions similar to those of billet rolling were gained.

3 Developments in the field of data acquisition, data transmission and data processing

Increasing variability and flexibility of production profile, accompanied by small lot sizes, lead to the risk that stress limit of machinery used in industry will not be easily comprehensible and thus calculable in future. Especially, this applies to production plants and large-scale plants of deformation industry, which have not been equipped with devices for detecting the actual stress conditions of their machinery continuously, up to now.

However, continuous detection of characteristic process-relevant parameters such as forces, torques, vibrations, temperature and the like, coupled with monitoring and evaluating up to process optimizing are considered to be imperative.

In the framework of a research project promoted by the government of the Federal Republic of Germany, VFUP Riesa e.V. developed an universal system of data acquisition, data radio transmission and data processing (called MOMERAS) which can be operated with mean up to high scanning rates and is moveably usable for totally enclosed sensors subjected to very rude ambient conditions and extremely dynamic states of motion.

Figures 17 – 19 below show partial components of this measuring system.

Figure 17: Mobile components of measuring system with connected 2000 kN load cell, universally usable

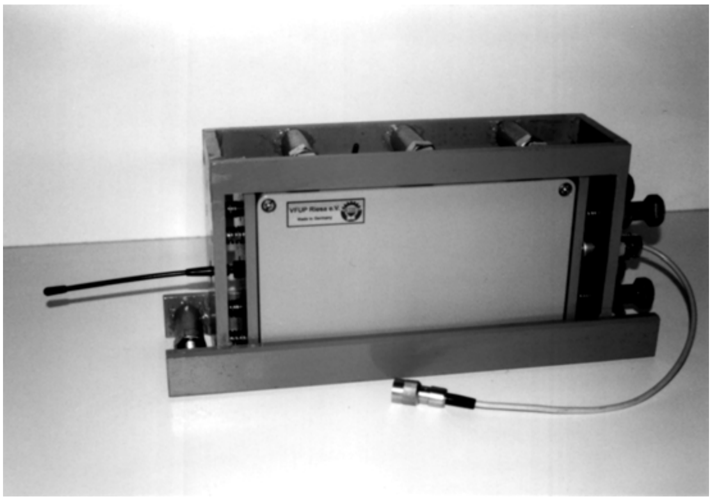


Figure 18: Mobile measuring system designed for use in protected and vibration-absorbed movable assemblies

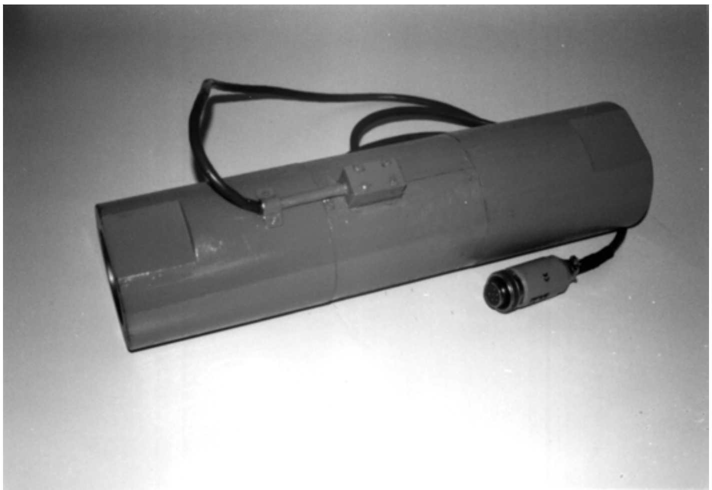


Figure 19: 2000 kN load cell especially usable at a push bench plant

This system is coupled with a wireless bus system (radio data network) based on bi-directional data transfer, which offers excellent mobility and variability, if used industrially.

This system of automatic control of measurement and data processing can be supplied ready for occupancy.

As the mobile components of this complex measuring system can also be operated by an accumulator battery, it is possible to further increase mobility and variability of this system.

Correction procedures (linearity control, temperature-dependent correction of zero and final values) and monitoring of limit and peak value will open up further fields of use of this system.

For all of the communication channels used with this system digitizing and signal processing is directly done at the place of measurement, without loss of information.

Up to 32 wireless measuring sequences to the corresponding locally distributed data sensors can be installed quickly and at a low expense, through the serial interface of a computer which has to be connected to a radio data modem base station via a converter.

The local radio data network installed in this way is suited for communication distances of up to some kilometres, depending on the selected transmitting power and the existing topographic conditions.

This complex measuring system can be completely controlled by a computer having a clear command syntax.

I general, the measuring system MOMERAS can be used with any machinery and plant, independent on the physical process parameters to be measured.

If ordered, VFUP will develop and manufacture data pick-up sensors with integrated system components required for special applications.

Up to now, this system has been used successfully for torque measurements at a cross rolling mill, force measurements at blooming mills and for the determination of pushing forces at a push bench plant.

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