FEELING FOR FINISHING

Flathoning and Lapping with Two-Wheel Machines

by
A.W. Stähli / B. Stähli

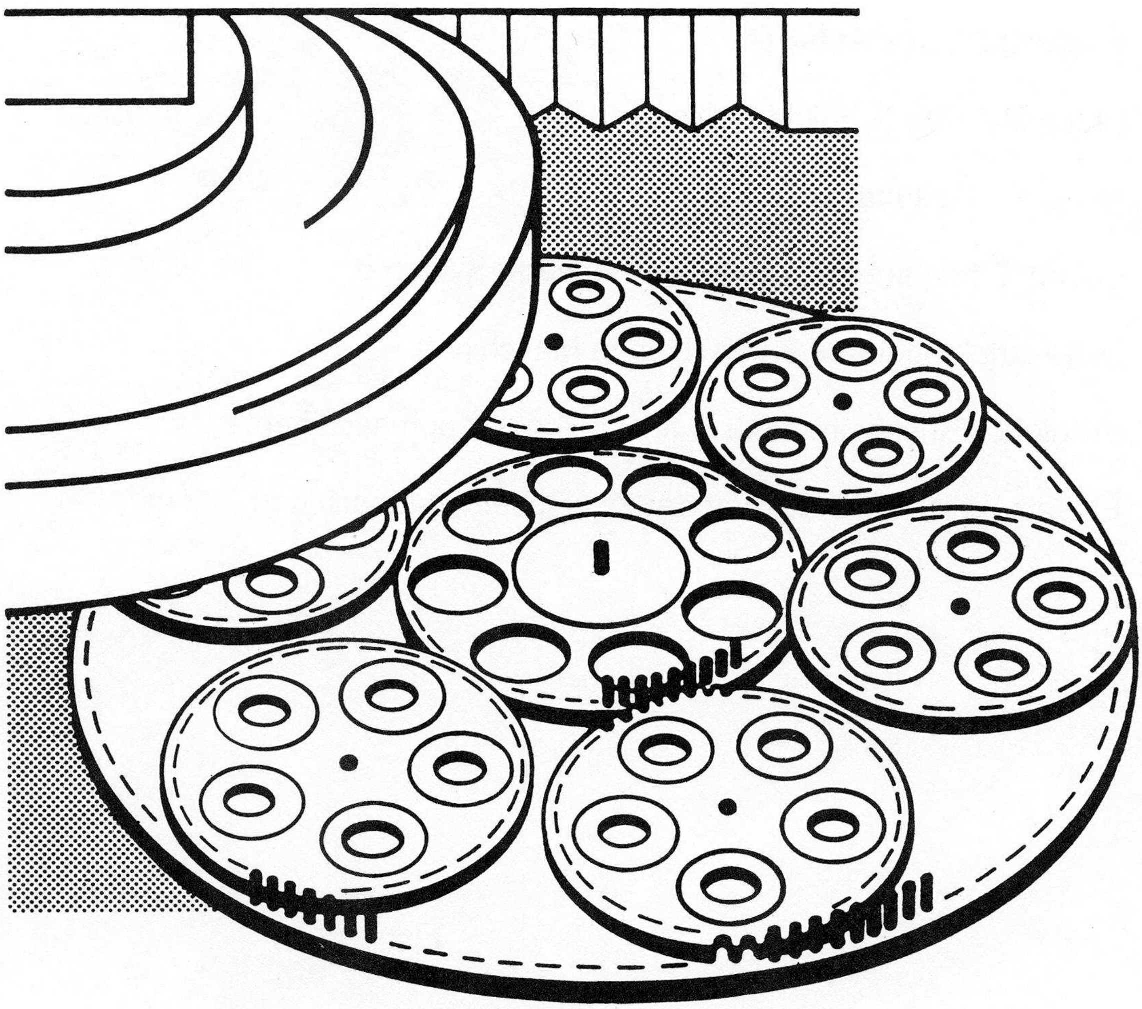

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Table of Contents

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List of Illustrations

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1. The principle

The term “two-wheel lapping/flathoning” refers to a stock-removal or cutting procedure between two rotating discs. This description explains how the discs rotate in relation to each other, how the work pieces are held and moved in the carriers between them and how the removal mechanisms behave. The text is kept as simple as possible and is designed to be easily comprehensible and instructive for average workers in practice and in the workshop. The theory involved has therefore been omitted to a large extent.

As with the single-wheel lapping machine, the origins of these procedures can be found in the Stone Age. Even at that time, grinding corn involved a type of rubbing of two surfaces against each other with the product in between. The corn (grain) makes a rolling movement between the discs until it breaks down under the pressure and becomes flour. (Cf. also Chapter 2 und reprint “Die Läpp-Technik” (“The Technique of Lapping”) by A.W. Stähli).

Figure 1: Mortar
(Drawing from Furrer Alex R. / Hartmann Fanny, "Vor 5000 Jahren" (“5,000 Years Ago”), Verlag Paul Haupt, Bern and Stuttgart, 1983)

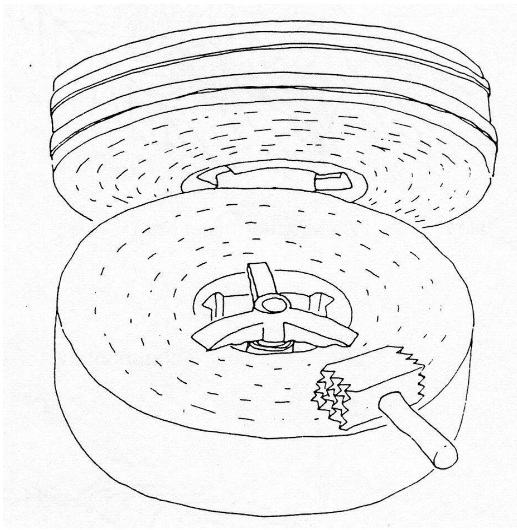


Figure 2: Millstone
Any spelt had to be removed before the grain could be ground. This was done in a rolling movement between two grooved stones, and the gap (slip) was measured so that the grain was only rubbed gently and not ground.

In our lapping procedure, the modern “grain” (produced synthetically and calibrated precisely) removes material from the work pieces inserted between the two discs.

The two-wheel lapping procedure is easy to understand and is more readily accepted as the acknowledged processing method than single-wheel lapping. For obvious reasons, it is also comparable to two-wheel grinding (cf. also Chapter 6 – Flathoning). It is also evident that, in this process, the material is removed on both sides but also in parallel. An initial view of and/or contact with this procedure does not reveal the full issue and the possible effects of wear on the two discs. However, a deeper study of the procedure is interesting and some research results from universities are available.

2. The basic lapping / flathoning process

As described in the reprint "Die Läpp-Technik" ("The Lapping Technique"), the removal process involves hard grain rolling on the work piece, which then moves in turn.

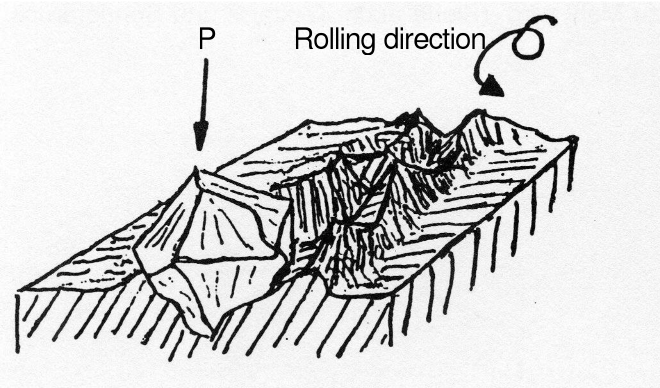


Figure 3: Procedure with loose grain

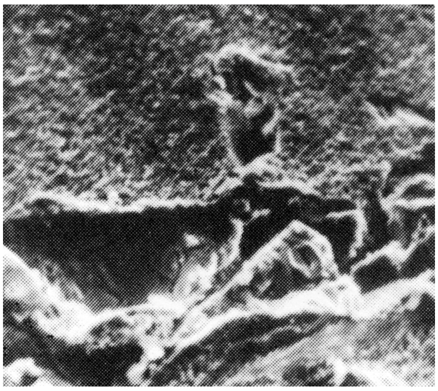


Figure 4: Removal procedure
Magnification approx. 3, 500 times

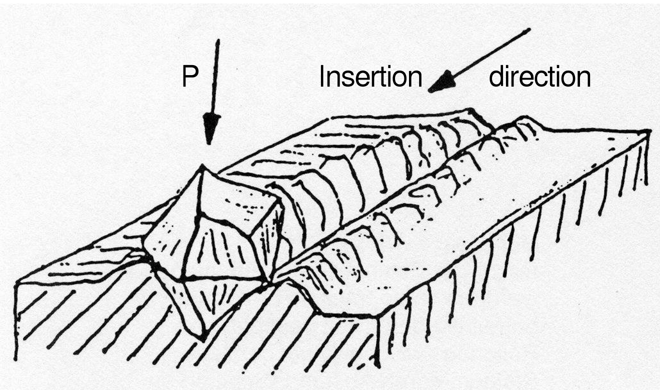


Figure 5: Procedure with bound grain

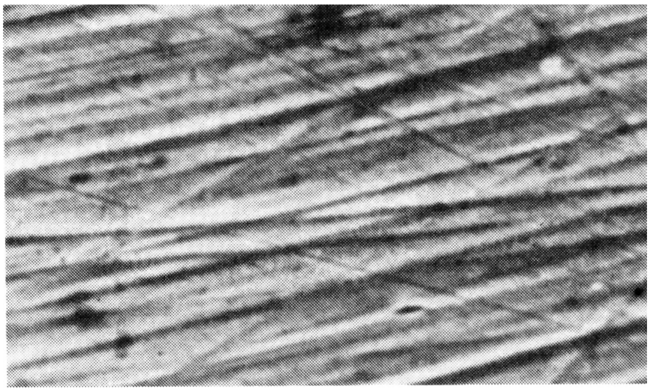


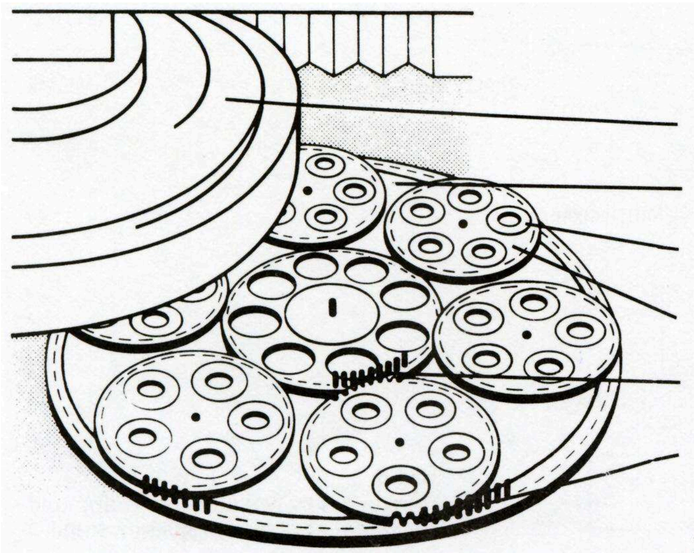
Figure 6: Honed surface of work piece
Work-piece surface honed with cutting grain
Material St 50, surface roughness Rt=0.5 µ, 1,350 times magnification

The procedure shown in Figures **3 + 4** requires a single-wheel lapping machine, as shown in Figure **7**, where dressing rings are used for holding the work piece and correcting wear. The work piece holders or jigs are positioned loosely in the dressing ring. The working wheel is dressed continuously during processing. As a result, a correction coefficient of over 100 % can be achieved by adjusting the dressing rings, which means it is theoretically impossible for a flatness error to occur.

Figure 7: Simple single-wheel lapping machine
View of a simple lapping machine

From Figure **8**, it is clear that the work pieces of the two-wheel machines must be held in so-called carriers or jigs. They are forced to rotate clockwise and are driven by a pin ring or toothed ring. In this way, the work pieces are drawn across the entire wheel surface. The upper working wheel is moved up as counter-pressure and the removal is carried out by the constant reapplication of the grain in between (Figures **3 + 4**). The upper and lower working wheels are driven individually and their speed and direction of rotation can be modified at will. Figures **5 + 6** show the "Flathoning" procedure, cf. Chapter 6.

In contrast to Figure **7**, we now turn to the two-wheel principle, which cannot use any dressing rings in the working process. The wear is only corrected by the arrangement of the work pieces, the shape and size of the work pieces, the exposure and the change of the rotation direction.



1 Upper working wheel

2 Lower working wheel

3 Work piece

4 Work holding plate (work piece receiver)

5 Inner pin or toothed ring

6 Outer pin or toothed ring

Figure 8: Two-wheel definitions

The exposure is determined and/or restricted by the type of the work pieces. The wear coefficient of the working wheels can be influenced strongly by the arrangement and number of the work pieces. It will never be possible for the correction coefficient to reach 100 %. It is occasionally necessary to interrupt production for additional dressing or cutting. An additional description of these important functions can be found in Chapter 8.

Characteristic properties of flathoning with planetary kinematics		
Machine set-up	Process technology	Work result
- Tension-free mounting of work pieces in a receiver cutout - Self-correction through oscillating suspension of upper working wheel - Force-linked feed, volume of time savings not strictly specified - Attractively priced devices for various work pieces - Short conversion times - Restricted to homogeneous functional surfaces (flat, concave, convex) - Variable processing of components in batches	- Even load over the entire functional surface due to laminar application - Direction of action parallel to work-piece surface - Comparatively low cutting speeds and grinding pressures, so only low temperatures and groove damage - Inhomogeneous load on grinding wheels - Cyclical change to the processing conditions due to planetary kinematics - Undefined microkinematics in autorotation of the work pieces	- Undefined curved, superimposed machining tracks (similar to cross-grinding) - Excellent surface qualities and shape accuracy - Improvement in the shape accuracy compared to the original status - Reduction in the divergence of thicknesses in the work pieces - Possibility to align functional and cladding surfaces for cylindrical work pieces - Fluctuating distribution of the grinding allowance on upper and lower sides of the work pieces - High removal volume/time - High G values

3. Description of a two-wheel machine

From a distance, a two-wheel machine may appear to be a simple machine without any real complexity. It only has two rotating working wheels with some lapping compound between them and a rotating pin ring. However, that is only true to a certain extent! The decisive factors are not only the mechanics, but also the know-how based on decades of experience.

Let's start by looking at the set-up.

On principle, we should differentiate between the design of lapping and flathoning machines. Excellent stability and extremely precise bearings are of crucial importance, as is the sensitive operation of the working wheels controlled by state-of-the-art technology. The lower section of the housing accommodates the bearing of the lower working wheel plus the inner and outer pin or toothed ring. The latter must be well protected against soiling, especially as the lapping compound and/or the removal are fatal for mechanical bearings. There is generally a closed-circuit cooling system for the working wheels. The coolant flows through up to three rotation axes, which are suitably sealed.

The carriers are each driven internally or externally by a pin ring or a toothed ring. These pins absorb considerable forces and it must also be possible to lower the outer one for the attachment of additional devices (cf. Loading and unloading fixtures, Chapter 10).

It should be easy to clean the entire working area. Good dirt drainage, a ring flush and a shower are necessary.

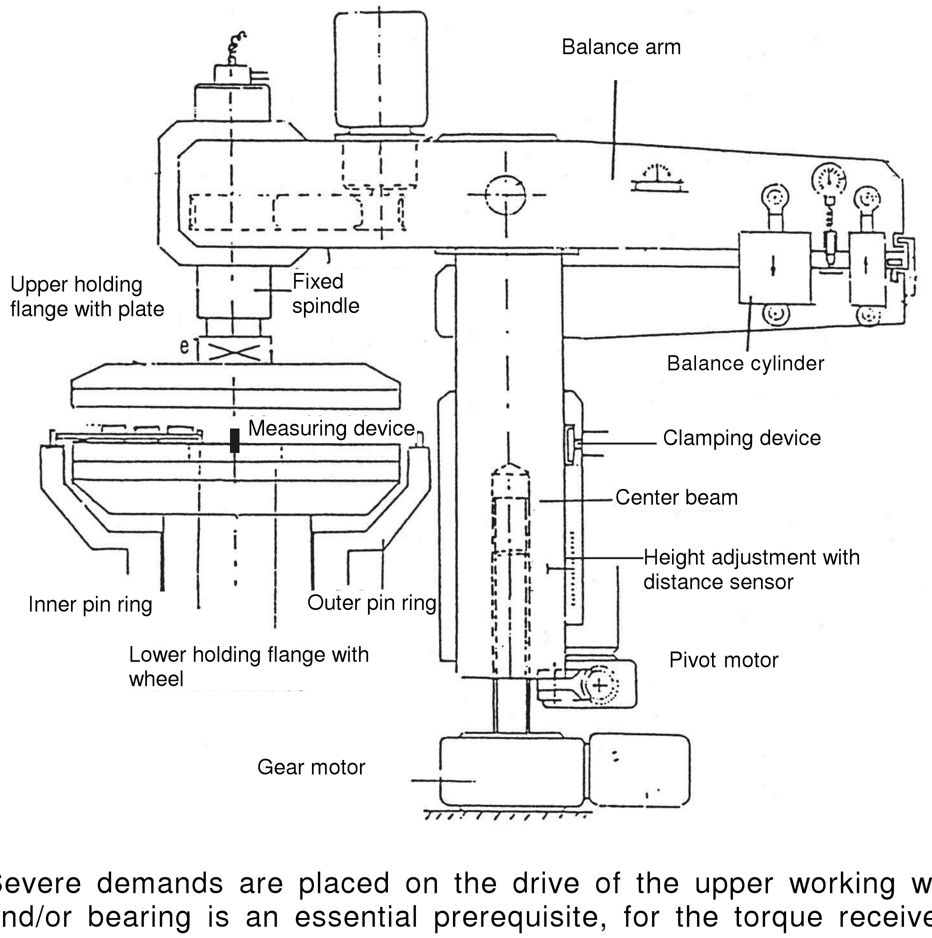


Figure 9: Machine principle
Principle of a two-wheel lapping machine

Severe demands are placed on the drive of the upper working wheel. A stable suspension and/or bearing is an essential prerequisite, for the torque receiver and the load control as well.

Mastering the load in connection with mechanics that are as reliable as possible, electronics and modern controls/algorithms is probably the most important, but also the most expensive area of the machine. In most cases, the heart of the machine is found in the types of bearing, suspension and infeed. In terms of the requirements, the upper working wheel must be as fast as possible and yet also position itself very gently on the work pieces. Firstly, its own weight must be compensated, and then it must be possible to regulate the load extremely precisely and with infinite variations theoretically from zero up to the highest end value. Because of the oscillating suspension of the upper working wheel, the coolant supply and/or return line must not be rigid, even if the upper section is pivoted away laterally and/or radially.

Production with controlled measurements demands the integration of measurement devices into the machine (in-process measurement). A central probe, fed through the upper spindle, is a possible variant. Direct measurements from the outside are generally more complicated and more expensive (Figure **34**).

Figure 10: DLM 700-3
Flathoning machines evolved from lapping machines

The following issues have to be mastered:

1. The high dead weight of the working wheel and/or the machine head (mass inertia)
2. A possible angle error between the upper and lower working wheels due to the various loads and manufacturer tolerances
3. The sensitive vertical adjustment of the upper drive spindle with its own friction in the seals, designated as “slip stick” or adhesion
4. The torque of the drive spindle must be built up from the outside via a spline shaft, a belt or direct drives. This generates considerable frictional resistance on the axial offset (infeed).

4. Features of the various series

The machines in the DLM series have solved the above-mentioned problems. We shall list and describe the main features with the following brief notes.

The **DLM** -03 **series** (Figure **10**) is designed with the pivoting balance beam, which compensates the weight of the machine head (Figure **9**), similar to weighing scales or a construction crane. This prevents rearing up due to the respective counter-forces. The quick and considerable vertical adjustments are carried out with a pneumatic or electro-mechanical vertical slide (Z-axis), and the precision in the range of 0.2 mm is sufficient. The adjustments are based on an adjustable stop or a travel-measuring system.

The precision infeed is carried out by precisely tilting the balance beam. The slight shift in the fulcrum that this causes has no effect. The zero setting is reached when the upper working wheel is positioned on the lower working wheel. The working spindle is mounted permanently and need not be shifted vertically. This makes the torque transfer extremely simple. The infeed of the various loads is simple and can be controlled precisely. This results in an entirely new level of precision. A self-locking function (securing) of the upper working wheel prevents any risk of danger in the case of a power failure. The machine head automatically pivots away laterally thanks to a pivot bearing in the machine head.

The **DLM** -05 **series** is the ideal flathoning machine and features a portal design. This gives the machine an extremely stable force progression and so an excellent contact-force dynamic. With its contemporary hydraulics, force sensors and corresponding algorithms, the contact force can be applied extremely dynamically, and so can be adjusted to suit the machining process. This series is also characterized by the fact that it is produced in steel/polymer from a single mould. This guarantees excellent internal damping while keeping costs low. The working area is compact and is designed for user efficiency.

Figure 11: DLM 705, two-wheel flathoning machine with loading and unloading table

The Duomat series of the Stähli Group was adopted in the production program upon the takeover of the lapping-machine program of the former company Hahn & Kolb, Stuttgart, and/or Bohner & Köhle GmbH ("Bokö"). Several thousand editions of the machines by Hahn & Kolb were built and are operating worldwide to the complete satisfaction of the customers (Figures **12, 13**).

Figure 12: ZL 501, Hahn & Kolb System series with loading/unloading table and pivot arm

Figure 13: ZL 700, Hahn & Kolb System series with working-wheel pivot system

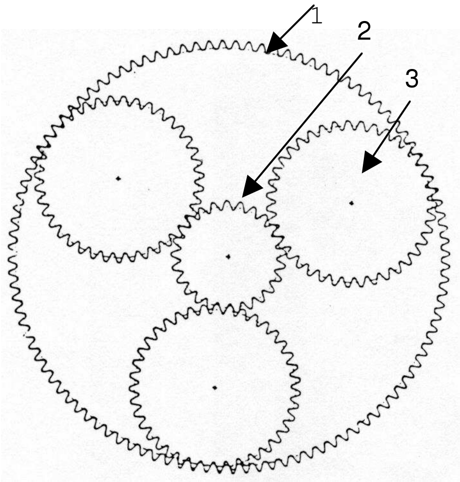
The solid design (cast housing) allows excellent performance on several materials. Thanks to modern valve technology, the hydraulics is extremely sensitive and makes it possible even to work on fragile work pieces. The feed of the upper working wheel is carried out in the machine head. The large adjustment travel even permits the use of thick fixed-grain wheels.

A hydraulic cylinder (X-axis) controls the lateral displacement of the machine head. The Z-axis has an integrated mechanical fall arrester, in case the power should fail. A powerful closed-circuit cooling system is designed to cool the working wheels, the hydraulics and the lapping fluid.

The integrated measurement control is regarded as the heart of all the series (DLM system): it is extremely precise and responds to an accuracy of 0.1 µ. Work-piece tolerances of < 2 µ are economically viable. An adjustable bar is attached to the lower working wheel, and acts as the base for the dimension sensor installed in the upper working wheel. The probe is mounted precisely by a rotary bearing (no rotation of the probe), and so the susceptible sliding contacts can be omitted as the connection to the measuring device and/or the machine control.

5. Machining tools

Like any other tooling machine, these machines also need so-called tools and aids.



1 Outer drive
2 Inner drive
3 Carriers

Figure 14: Basic diagram with three carriers

The system with driven work-piece receivers (carriers) requires a suitable set for virtually every type of work piece. The number of work pieces – usually between three and seven – and the work-piece exposure determine the diameter of the working wheels. A recommended rule states that approx. one third of the work-piece surface should be exposed to the inner and outer diameter of the working plates. However, this depends to a great extent on the shape, the material and the thickness of the work pieces. Thin work pieces and thin rings permit less exposure. Another criterion is also the thickness of the carriers, which must be determined for every type of work piece.

Lapping compounds

The lapping compounds and their use are more restricted for two-wheel lapping machines than for single-wheel lapping machines. At present, aluminum oxide, SI-C, boron carbide or compounds of them are still being used. The carrier liquids vary from water to oil with specified viscosity. In the process, chemical additives are required to guarantee the moistening of carriers of the grain (suspension behavior) and anti-rust protection. Oil-based liquids are more advantageous, because they dry out less and form a good grain film.

The water-based mixture ratio (powder to liquid) stands at 0.2-0.5:1 or approx. 200-500 g powder per liter of liquid.

The oil-based mixture ratio (powder to liquid) stands at 0.1-0.2:1 or approx. 100-200 g powder per liter of liquid.

The consumption for a single-wheel working wheel diameter of 750 mm it is 4-5 L/hour on a water basis and to 2-3 L/hour on an oil basis. The consumption for two-wheel working wheels is approximately double.

Special gray cast iron, steel, nonferrous heavy metal or lightweight metal, fixed grains and textile pads in various designs are used for the working wheels. The surface structure may be full, slotted or cross- or spiral-grooved, depending on the type and use of the lapping compounds and of course the shape of the work pieces.

The lapping-compound mixture and its supply to the working zone need a good pump system with constant mixing and precise metering. Experience has shown that a constant tank level is extremely useful for ensuring a regular feed. An additional tank with a cooling system and containing the volume for a day's consumption guarantees regular daily production.

The used lapping compounds and of course the stock removal and the wheel wear must be disposed of properly. A powerful ring flush and shower are extremely useful. A fine-filter system is also worthwhile for large-scale consumers.

Flathoning tools

Thanks to the use of fixed-grain wheels (flathoning), the level of dirt created is much lower. The fixed-grain wheels use a flood rinse, which carries the dirt into a filter system outside the machine and makes the liquid reusable (clean lapping, Figures **15, 16**).

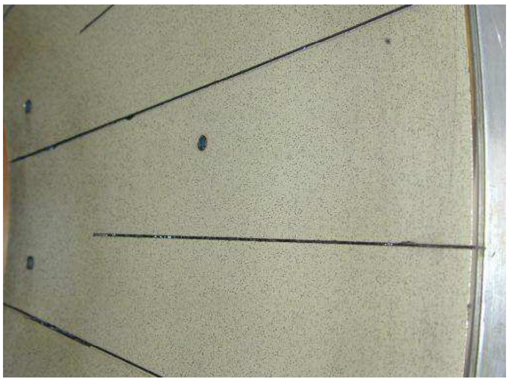


Figure 15: Full wheel design with grooves

Figure 16: Pelleted wheel design

Here, one must differentiate between synthetically bound and ceramically bound wheels. Thanks to the relatively low cutting speeds of 1-25 m/s, it is possible to easily solve thermal machining problems such as the material type (plastics) and distortions of shape.

Figure 17: DLM 803 with cooling and filter system (3 working wheels = 2 workstations)

6. Flathoning – “clean lapping”

The required specification for lapping- and polishing-machine manufacturers is shorter machining times achieved in an ecologically friendly environment. New work pieces and/or new materials are constantly being developed for use with new applications.

Definition

Flathoning uses the principle of planetary kinematics. In French, we call this working process “la rectirodologie” (rectifier = grinding, roder = lapping). Fine grinding is another term that largely corresponds to this working process. Our slogan “Clean lapping” refers to the highest possible level of quality combined with clean methods.

Machining

At relatively low cutting speeds (compared to grinding), flathoning offers the benefit of comprehensive tool application instead of linear contact as in grinding. The work is carried out at a low specific pressure, unlike in grinding where the specific pressure is quite high and can cause burned areas. Corundum, silicon, CBN or diamond working wheels (bound) in various grain sizes and bindings are used for the cutting process, instead of the process with a loose grain. Thin honing oil or water and a small quantity of generally biologically degradable additives are used as the coolant. The coolant is cleaned continuously by a filter system in a closed circuit. In order to understand the procedure between the work pieces and a working wheel better, it is worth studying various research papers and the easy-to-understand reprint “Lapping technology” by A.W. Stähli. The latter work focuses particularly on practical elements.

Accuracy

The main advantages of the flathoning technique are its excellent geometrical results, which correspond to lapping quality and can be adopted for most materials. Customized tolerances fall in the range of 1 µm depending on the work-piece shape, 0.3-0.6 µm for flatness, 0.5-1 µm for parallelism and up to Ra 0.025 µm for the surface quality, depending on the material. The prerequisite for such results is the right choice of working tools.

Cleaning

This innovative machining technique produces clean and glossy surfaces. It also permits easy cleaning of the work pieces, as only a gentle rinse is necessary. This is crucially important both for production and for checks.

Advantages of this technique

The stock removal is far greater than with conventional lapping. The “cut-up” material surface (drawn grain) produces glossy surfaces and shorter machining times. Operations such as cutting and grinding can be omitted. Other major advantages are that virtually all materials can be machined, and the removal rates lie between 0.01-1 mm per minute, depending on the material, the surface size and the required surface quality. In certain working processes, this technology also permits the elimination of one or more work phases, which helps to reduce the machining costs dramatically.

The company Stähli Lapping Technology Ltd has developed the relevant flathoning technology from its knowledge of two-wheel lapping and has integrated all the necessary machining parameters into its DLM series (Figures **10, 11, 17**). Options with semi- and full automation have also been developed and have proved their value in widespread production.

Outlook

The various refinishing centers of the A.W. Stähli AG Group are working constantly to guarantee continuous enhancements with the specifically required equipment in each case. This ensures progress for a wide variety of requirements and customer wishes in the field of high-precision machining. Finally, we can sum up by saying that the described new technology of flathoning or fine grinding provides an extremely economical working process in the high-precision machining sector. It also satisfies the constantly increasing and justified requirements of environmental protection.

7. Work pieces and removal

In terms of the type of work pieces, the two-wheel machining process is more limited than single-wheel lapping machines, particularly in relation to the height of the contact surface.

Virtually all materials can be machined. However, the work pieces should have a certain thickness, as the machining forces are applied twice, depending on the rotation or counter-rotation of the working wheels.

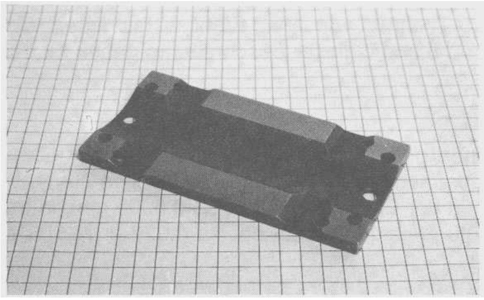


Figure 18: Machining example
"reinforced steel plate"

Figure 20: Machining example
"plastic pump lid"

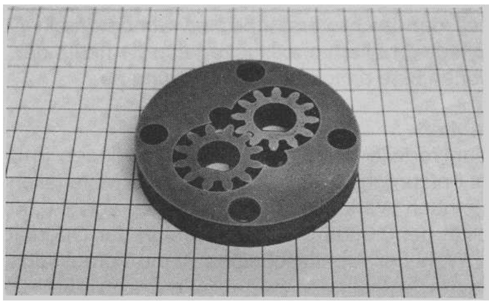


Figure 19: Machining example
"toothed-gear pump set made of sintered metal"

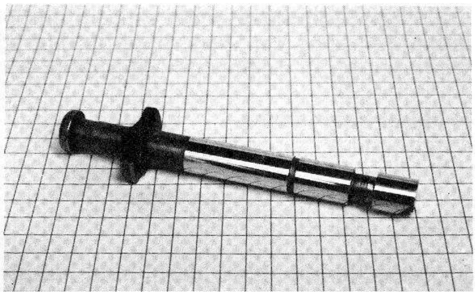


Figure 21: Machining example
"hydraulic volume regulator, cylind. lapped"

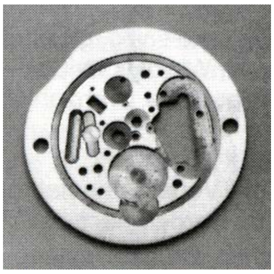


Figure 22:
Machining example
"clock circuit board, brass"

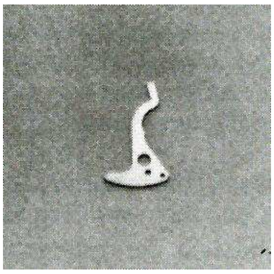


Figure 23:
Machining example
"bar, steel"

Figure 24:
Machining example
"hard-metal circular knife"

Necessary data for machining
- Drawing of the work pieces
- Material and hardness
- Pre-machining and allowance
- Outer dimension, outer shape, interrupts, unevenness, removal on one side, two sides, equal
- Surface quality, flatness, parallelism, dimension and tolerances, grain selection, angularity, CPK values
- Definition of: working process, working wheels, carriers, speeds, level loads, loading and unloading systems, etc.

In order to compensate for differences and irregularities, the system starts up with a preload. This is then followed by the main load, which is held shortly before the correct dimension. It can be calculated according to the definition of the working wheels, the work-piece surface and the permissible, specific pressure load per N/cm^2. The post load is used to equalize (like sparking out in grinding).

Notes for machining:

1. The user must be able to determine how the removal is proceeding via the information display. If the machine is working too dryly, with too great a load or with dirt, the power consumption will increase. An increase in the machining time also indicates a fault. A constant level should be achieved during the machining time.
2. The speed and the liquid volume should be selected so that the lubricant film is always clean and fluid and optimal stock removal is guaranteed. Any jerky running under load indicates irregularities.
3. Considering the machining time, the dimension constancy, the roughness, the flatness and the parallelism can help you to draw conclusions about the status of the operating working wheels. Any negative changes must be countered in good time.

18-3 18-4
18-5 18-1
18-6 18-2

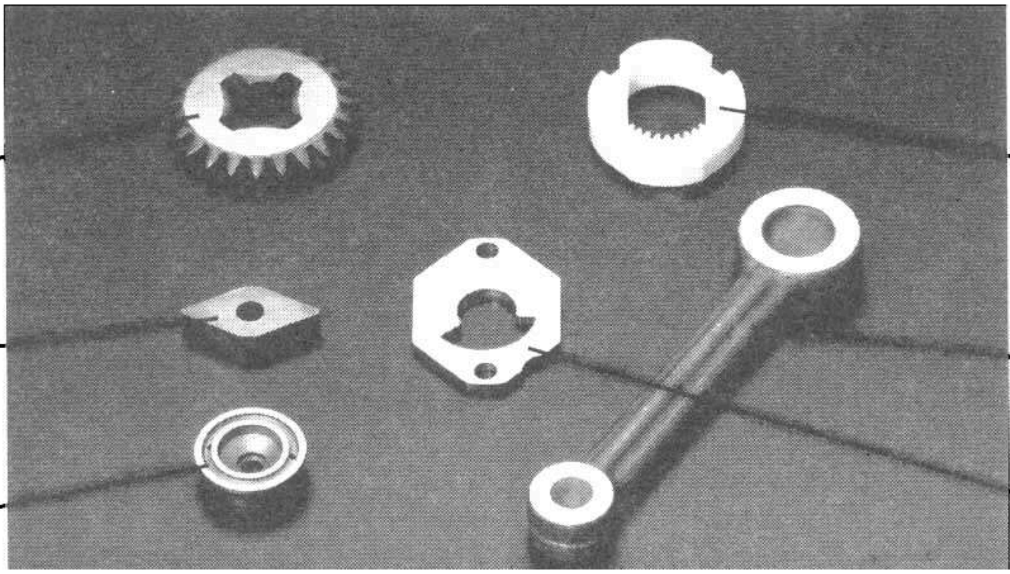


Figure 25: Work pieces processed with loose and fixed grains

18-1: Diecast aluminum connecting rod, Ø 30 x 100 x 12 mm, blank with over 1 mm allowance, cutting in 1 minute per load of 60 items, DLM 700, diamond D76, loading/unloading time with pulse system 1 minute (flathoning)

18-2: Intermediate plate in steel, Ø 40 x 15 x 3 mm, allowance 0.1 mm/side, punched, machining time 15 minutes per load of 100 items, DLM 700, cast-iron wheels, SiC-500, lapping oil (lapping)

18-3: Cutting wheel, Ø 35/12 x 6 mm, made of steel, allowance 0.2-0.3 mm, punched-pressed, machining time 2 minutes per load of 180 items, DLM 1000, D 126, honing oil (flathoning)

18-4: Ceramic disc made of Al_2O_3 Ø 35/15 x 5, allowance 0.4 mm, raw sintered part, machining time 1 minute per load of 65 items, DLM 700, D 76, honing oil (flathoning)

18-5: Indexable insert, approx. 25 x 13 x 6 mm, made of hard metal, unilateral allowance 0.1, opposite side 0.05, machining times 3 minutes per load of 200 items, DLM 700 with D 46, honing oil (flathoning)

18-6: Intermediate plate, Ø 20 x 6.5 mm, allowance 0.1-0.15, lathed, machining time 1.5 minutes per load of 200 items, DLM 700, D 46, honing oil (flathoning)

8. Keeping the working wheels flat

As the removal performance increases, the wear factors also become more significant. The following faults may occur:

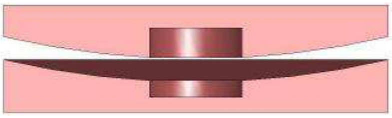
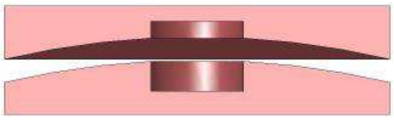
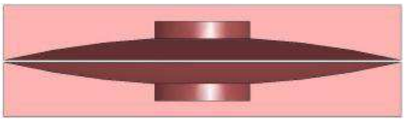
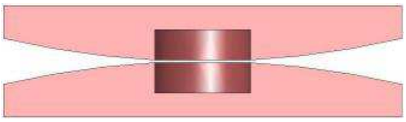
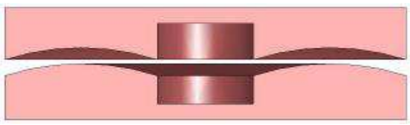
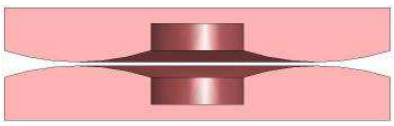
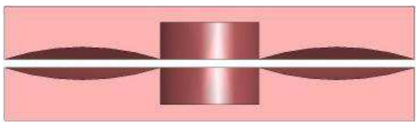
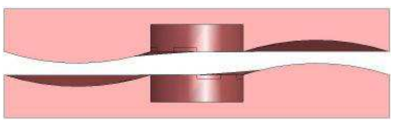
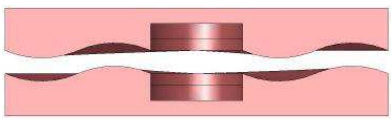
1.		Excessive wear on the inside of the lower working wheel. Upper working wheel adapts below. Observe change of direction in the carriers: rotation/counter-rotation.
2.		Excessive wear on the inside of the upper working wheel. Lower working wheel adapts above. Observe change of direction in the carriers: rotation/counter-rotation.
3.		Excessive wear on the inside of the upper and lower working wheels. Wheel design in the inner zone too weak, so increase inner concentration.
4.		Excessive wear on the outside of the upper and lower working wheels. Wheel design in the outer zone too weak, so increase outer concentration.
5.		Excessive wear in the ring of the lower working wheel. Too many parts in the center of the carriers with strong downward wear factor.
6.		Excessive wear in the ring of the upper working wheel. Too many parts in the center of the carriers with strong upward wear factor.
7.		Too frequent change of direction in the carriers. Insufficient parts in the inner ring of the carriers.
8.		Excessive wear load in the ring of the upper and lower working wheels. Too many parts in the inner ring of the carriers or too little exposure.
9.		Undulations in the working wheel due to uneven arrangement, uneven hardness and so uneven wear factor on the working surfaces.
10		Insufficient correction of faults above through the implemented counter-measures due to: - data changes on the machine made too early - change of work-piece type too early

Figure 26: "Keeping flat" overview of faults

It is possible to initiate counter-measures in good time by regularly monitoring and frequently measuring the working wheels and the work pieces. There are various possibilities for doing this:

Flatness measurements on the working wheels of two-wheel lapping machines

1. Check procedure

It is possible to determine the status of the working wheels with flatness measurements. They can be carried out in two different ways:

a. Using an inspection straightedge, which only shows whether the working wheel is convex or concave.
b. Using a precision straightedge – fitted with dial gages (Figure **27**). This variant displays the precise fault on the working wheel. A minimum of two measurements, each offset by 90°, show the precise status of the working wheel and also any possible undulations.

   Number of measurements on the working wheels: min. 2 x per day (upper and lower working wheel)

   Note: The test paths on the working wheel must be cleaned well. Enter the measured values in an inspection sheet (cf. Figure **28**). If in doubt, repeat the procedure.

In the interests of monitoring the results, it is also important to specify the settings of the machine.

- Speed of the upper working wheel, direction of rotation and time in direction-change cycle 2
- Speed of the lower working wheel, direction of rotation and time in direction-change cycle 2
- Speed of the inner pin ring, direction of rotation and time in direction-change cycle 2
- Speed of the outer pin ring, direction of rotation and time in direction-change cycle 2
- Working-wheel pressure load in three stages or variably, e.g. 1 = 100, 2 = 500, 3 = 300 daN

In the version with a drive for the outer pin ring and in connection with the speed of the inner and outer pin rings, it is possible to have the carriers rotated very quickly or very slowly between the wheels or in their standard position! This option is referred to as the “fourth way” or “fourth axis”. In this case, it is again important to note down the speed, direction of rotation and time.

In the process, note the work-piece progress on the working wheel. Varying exposure curves can be produced depending on the rotation, counter-rotation and speeds. Cf. Appendix, Figure **39** Epicycloids and hypocycloids.

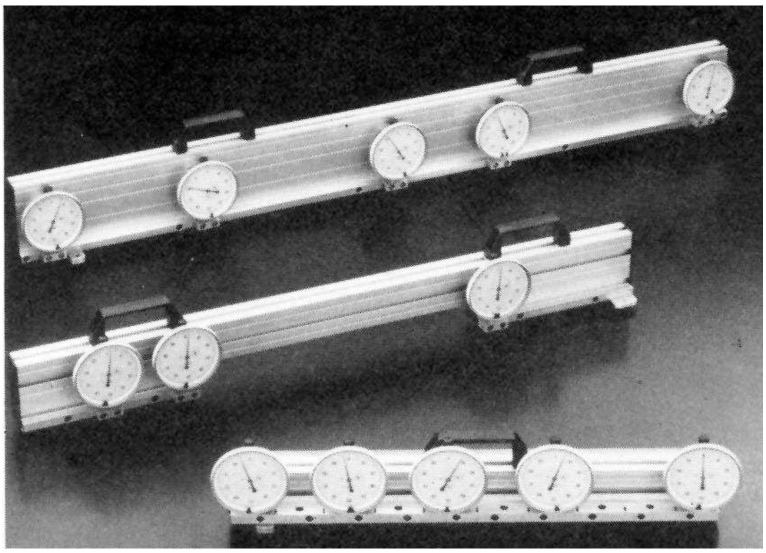


Figure 27: Inspection straightedges of various sizes

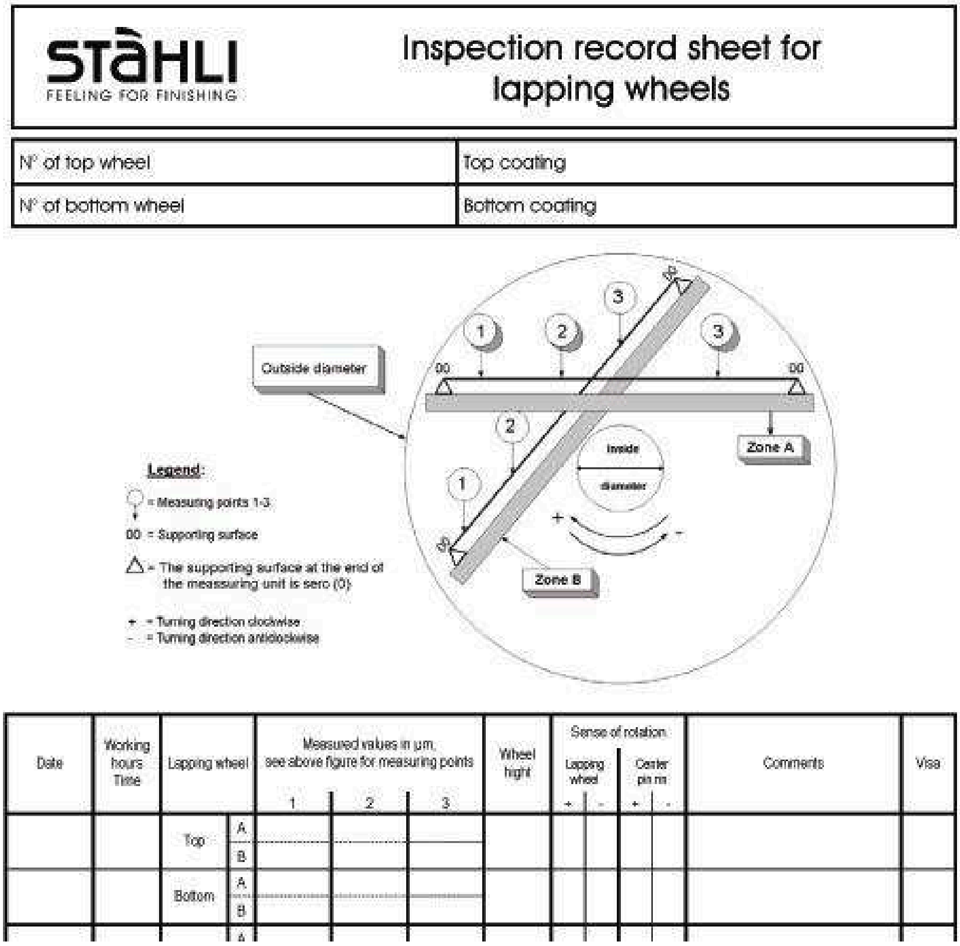


Figure 28: Inspection sheet for DLM working wheels

2. Dressing of the working wheels

The text below provides basic specifications. Practical experience has shown that the theory often does not match the values on the work pieces measured in practice and the corrections on the machine. Frequent measurements and logical thinking will help you to harmonize the theory and actual practice better.

Machining work pieces with loose or bound grains involves several unknown factors, which may have an influence. The following list simply shows some data which you must know and enter in a workcard:

- The technical values and faults of the supply to work pieces to be machined, dimensions, position and quantity per work holding plate.
- Designation, number and material of the working plates, hardness, surface condition, full, slotted or grooved with specification of the gradient, binding, etc.
- Drawing or production number of the carriers, quantity, material, with and without documentation.
- Applied clapping compound and fluid, including volume, mixture ratio.
- Pressure and time of the three working cycles and pressure load per cm^2 work surface area on the work piece.
- An empty column for comments.

In most cases, we register a change in the working wheels after Positions 1-4, 8 (Figure **26**). Pos. 8 is due to an excessively high positioning in the center of the carriers. The fewer work pieces we place in the center of the work holding plate, the more regular is the cutting speed between the different work pieces and the wear on the working wheel. In practice, it is necessary to find a compromise between the ideal number of allocated work pieces, their arrangement in the carriers and the tolerable wear. Figures **29-32** show the four versions of the possible variations in the direction of rotation and must be studied in order to avoid more serious flatness faults in good time. Enter all measuring results and procedures in the inspection card!

Explanation of symbols:

e	=	Outer working zone (external)
i	=	Inner working zone (internal)
Ve	=	Outer cutting speed
Vi	=	Inner cutting speed
Ve1+Vi1	=	Speed of the lower working wheel
Ve2+Vi2	=	Speed of the upper working wheel
V	=	Cutting speed
Vw	=	Speed of work piece
U	=	Wear of working wheel
r	=	Direction of rotation to right (clockwise, viewed from above)
l	=	Direction of rotation to left (counter-clockwise, viewed from above)

VERSION 1

Direction of rotation (viewed from above)
- Upper working wheel counter-clockwise
- Carriers clockwise
- Lower working wheel clockwise

The cutting speed -V- and the resulting wear -U-

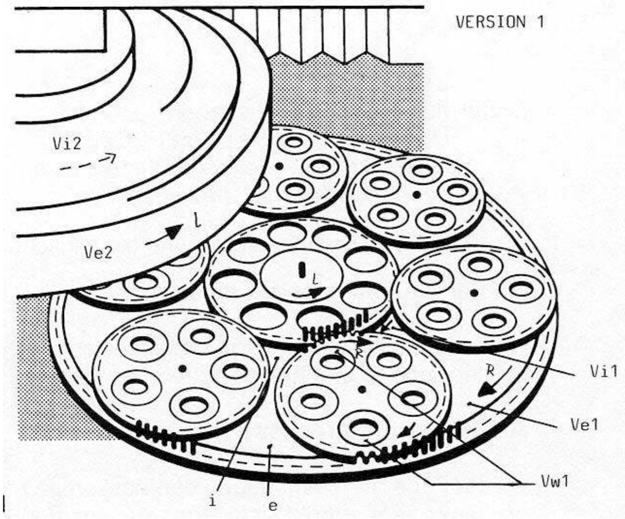
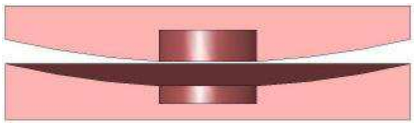


Figure 29: Wheel behavior, version 1

On the upper working wheel
-V- in the zone "e" increases in relation to outer diameter
"e" Ve2 + Vw1
-V- in the zone "i" falls in relation to inner diameter
"i" Vi2 – Vw1

On the lower working wheel
-V- in the zone "e" falls in relation to outer diameter
"e" Ve1 – Vw1
-V- in the zone "i" increases in relation to inner diameter "i"Vi1 + Vw1

Theoretical conclusion about deformation of working wheels
Upper working wheel - convex
Lower working wheel - concave



Correction recommendation
Reduce the speed of the upper working wheel and increase the speed of the lower, and/or change the direction of rotation of the center drive.

Note:
The speed regulation of the working wheels and carriers allows you to influence the wear on the working wheels, and so to improve their flatness. During set-up, pay careful attention to the speed and direction of rotation of the working wheels, the carriers and the change times.

VERSION 2

Direction of rotation (viewed from above)
- Upper working wheel clockwise
- Carriers counter-clockwise
- Lower working wheel counter-clockwise

The cutting speed -V- and the resulting wear -U-

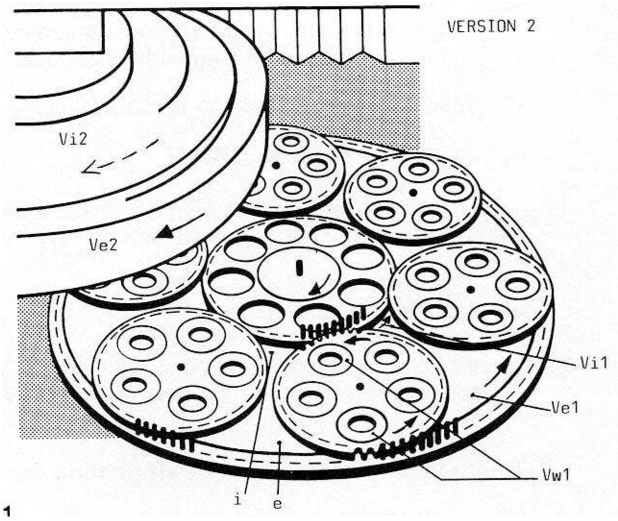
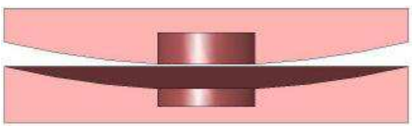


Figure 30: Wheel behavior, version 2

On the upper working wheel
-V- in the zone "e" increases in relation to outer diameter
"e" Ve2 + Vw1
-V- in the zone "i" falls in relation to inner diameter
"i" Vi2 – Vw1

On the lower working wheel
-V- in the zone "e" falls in relation to outer diameter
"e" Ve1 – Vw1
-V- in the zone "i" increases in relation to inner diameter
"i" Vi1 + Vw1

Theoretical conclusion about deformation of working wheels
Upper working wheel - convex
Lower working wheel - concave



Correction recommendation
Reduce the speed of the upper working wheel and increase the speed of the lower, and/or change the direction of rotation of the center drive.

VERSION 3

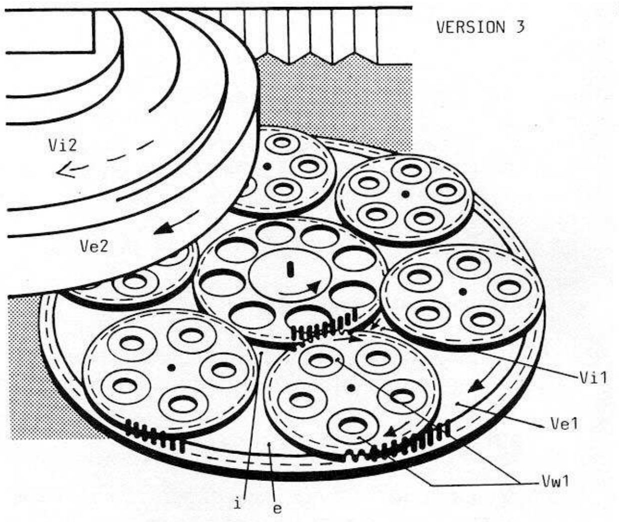


Figure 31: Wheel behavior, version 3

Direction of rotation (viewed from above)

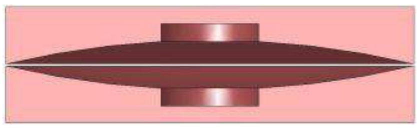
- Upper working wheel clockwise
- Carriers clockwise
- Lower working wheel clockwise

The cutting speed -V- and the resulting wear -U-

On the upper working wheel
-V- in the zone "e" falls in relation to outer diameter "e"
Ve2 – Vw1
-V- in the zone "i" increases in relation to inner diameter "i"
Vi2 + Vw1

On the lower working wheel
-V- in the zone "e" falls in relation to outer diameter "e"
Ve1 – Vw1
-V- in the zone "i" increases in relation to inner diameter "i"
Vi1 + Vw1

Theoretical conclusion about deformation of working wheels
Upper working wheel - concave
Lower working wheel - concave



Correction recommendation
Reduce speed of the carriers and/or change the direction of rotation of the center drive.

VERSION 4

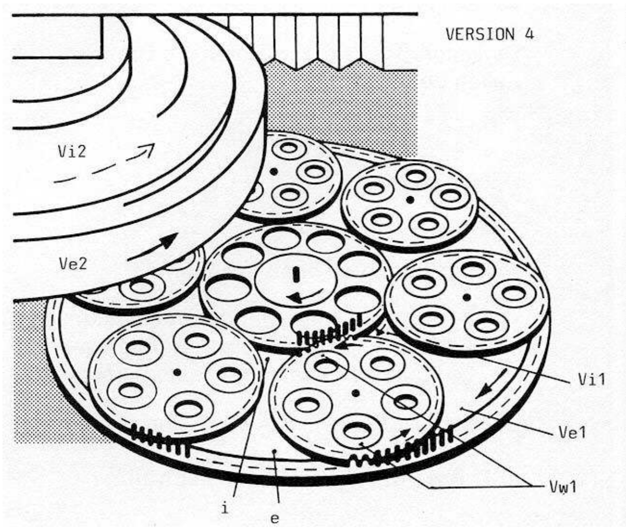


Figure 32: Wheel behavior, version 4

Direction of rotation (viewed from above)

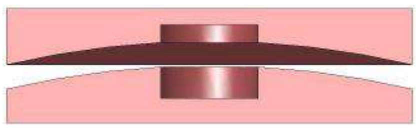
- Upper working wheel counter-clockwise
- Carriers counter-clockwise
- Lower working wheel clockwise

The cutting speed -V- and the resulting wear -U-

On the upper working wheel
-V- in the zone "e" falls in relation to outer diameter
"e" Ve2 – Vw1
-V- in the zone "i" increases in relation to inner diameter
"i" Vi2 + Vw1

On the lower working wheel
-V- in the zone "e" increases in relation to outer diameter
"e" Ve1 + Vw1
-V- in the zone "i" falls in relation to inner diameter
"i" Vi1 – Vw1

Theoretical conclusion about deformation of working wheels
Upper working wheel - concave
Lower working wheel - convex



Correction recommendation
Reduce speed of the carriers and/or change the direction of rotation of the center drive.

Other possibilities for correcting the working wheels:

- Dressing the working wheels during lapping is carried out using slotted dressing rings made of special gray cast iron that are driven by toothed gears.
- Dressing the working wheels during flathoning is carried out using abrasive products inserted in the cages.
- Flat lathing or grinding is another solution, but will probably be the most expensive.

Dressing, either periodically or at the end of a working day, reduces the running times and, with optimal use, increases the service life of the working wheels. It is particularly necessary to use this procedure when the work pieces to be machined need to possess an extremely precise flatness tolerance.

The quality of the flatness and the parallelism of the work pieces will remain constant if the machine is well maintained and checked regularly by the user and the speeds and the directions of rotation of the carriers and the working wheels are varied. In order to achieve this result, the user must carry out the technical measurements regularly and methodically (cf. Figures **27, 28**). The applied corrections on the machine must be tried out first before any further corrections are made. It is always advisable to consider what may be causing the fault, and then to take the necessary counter-measures in good time. The corrections must be entered regularly in the inspection card.

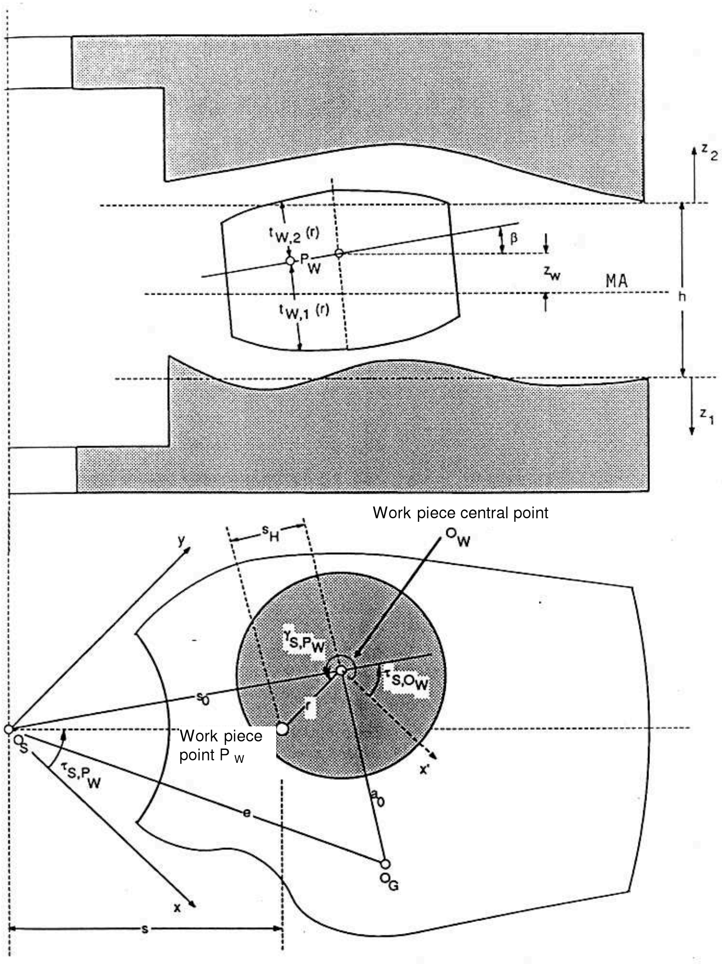


Figure 33: Geometry of the two-wheel process
Progress of a round wheel
on faulty working wheels
(Dr. Kling, ETH Zürich 1990)

Figure **33** shows the cutting field that the work pieces must pass through on faulty working wheels. It would be interesting to be able to determine the splitting pressure. This may range between an extremely high pressure load and lying entirely free. The lapping or liquid film will be extremely uneven, and it may even break. It is quite clear that the shortest machining time and the best quality are produced if both working wheels possess perfect flatness.

9. Measuring – results

The thickness dimension of the work pieces is measured directly on the machine using the centrally installed gauging probe during the work process. Tolerances of less than +/- 1 µ are economically possible, depending on the condition of the machine, the working wheels, the gauging probe and the type of the work pieces.

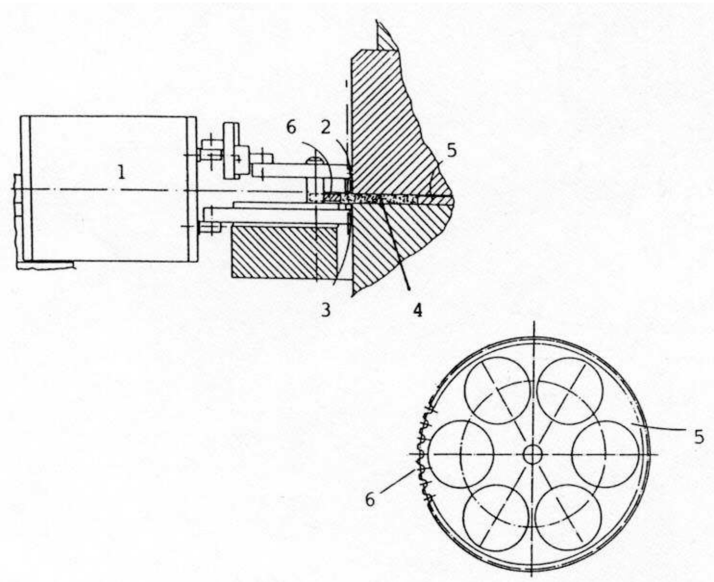
The parallelism of those surfaces in good conditions should lie within tolerances of less than 1 µ for a work piece of 100 x 10 mm diameter on a machine with a working-wheel diameter of 1,000 mm. Results have been known from practical experience where work pieces of diameter 300/100 x 8 mm on a machine with a working-wheel diameter of 1,500 mm can still be machined to the perfect co-planar dimension at under 2 µ. This example is designed to show that the flatness of the working wheels must not be neglected. A fault can cost a great deal of time and money.

The surface quality of the work piece depends on the final load, the grain, the medium and the condition of the working wheels. Irregular surfaces bear witness to uneven progress between the working wheels, where you should also search for signs of a flatness fault. When using loose grains such as Si-C and B4C, the lapping surfaces are generally matt gray, but they satisfy the requirements in most cases. If diamond liquids or bound grains (fixed-grain wheels) are being used, the surface will appear bright and reflective, as if it was honed or similar to cross-grinding. In the latter machining method, the surfaces are easier to clean and check.

The measuring devices for both direct and indirect process measurement are well-known.

- Indirect or in-process measurements are carried out by the central gauging probe which is permanently installed in the machine (most common procedure).

- Direct measurements on the work piece during the process from the outside can cause problems in terms of the wear on the gauging probe, reliability and soiling (Figure **34**).



1. Measuring device
2. Upper gauging probe
3. Lower gauging probe
4. Work piece
5. Work holding plate
6. Toothing on work holding plate

Figure 34: Measuring device for direct measurement from outside

The following should be noted for direct measurements from outside: there is the problem of work pieces overhanging the outer diameter of the working wheels, and the related soiling and possible damage by the probe. It is therefore only possible to measure relatively large work pieces with greater exposure. It is also impossible to comment on the flatness or coarseness.

10. Additional fixtures, loading and unloading systems

An important function after the machining process is the unloading and/or loading of the machine with carriers and/or work pieces. The retraction (raising) of the upper working wheel by a small distance plays an important role in ensuring the efficient and safe loading and unloading of the machine.

It is necessary to lower the outer pin ring to allow the loading and unloading procedure with the loading/unloading table and the carriers. This forces the user to engage the carriers carefully into the mesh of the gears when inserting them.

Thanks to the position control of the center drive and the appropriate partial lowering of the outer pin or toothed ring, it is possible to load and unload both manually and automatically. This function can also be combined so that you load on one side and unload on the other.

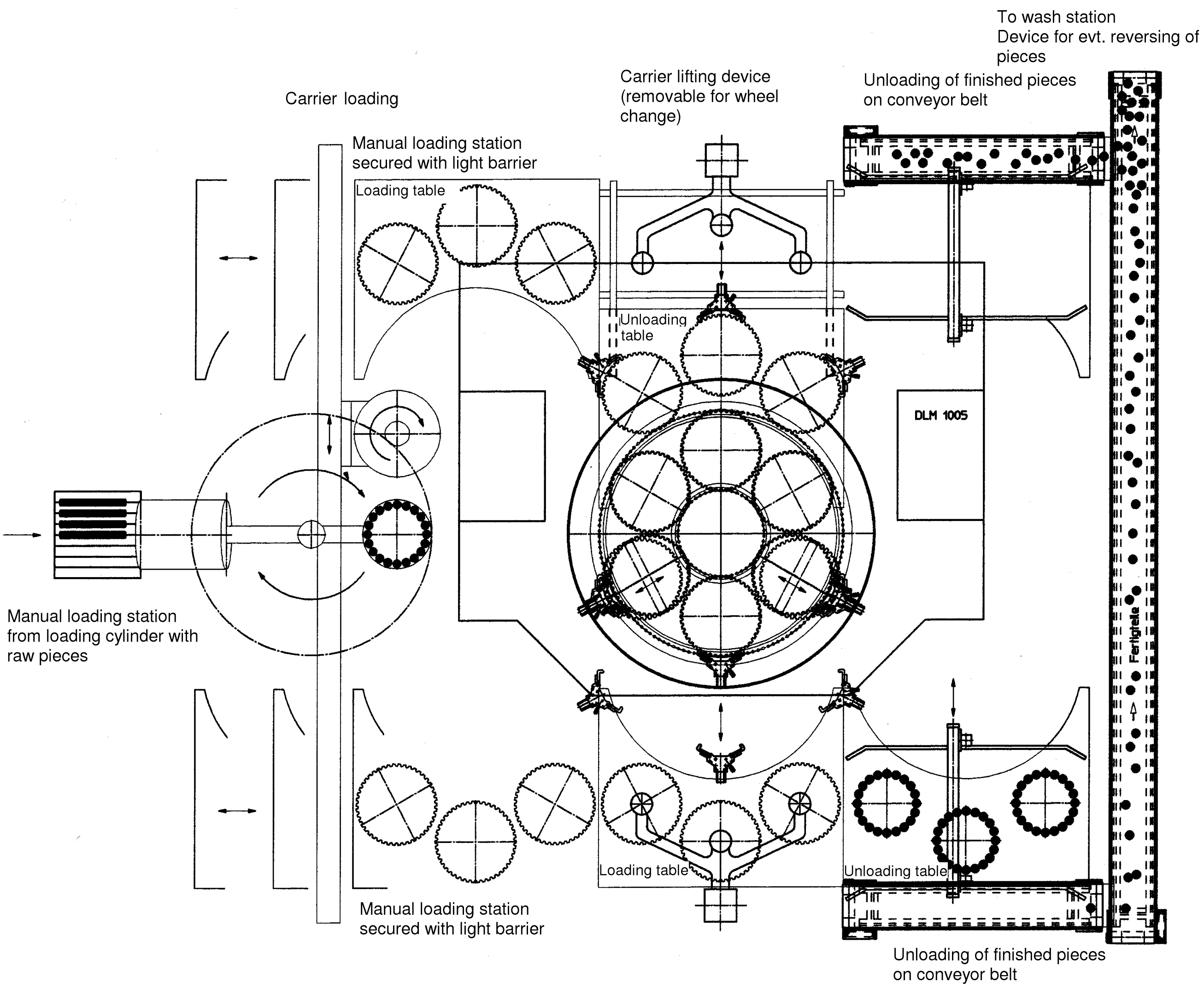


Figure 35: Solution for a fully automated flathoning machine

To allow the machines to achieve their full efficiency, it is necessary to pay more and more attention to all of the related circumstances. The machine manufacturers are being encouraged to produce integral solutions, for instance to automate the working process, cleaning, checking, packaging, etc.

Fixtures of all kinds, such as the loading and unloading table (Figure **10, 11, 36**), are well-known. They allow you to load the work pieces into the carriers while the machine is running.

In the same way, “tricky” work pieces can be placed carefully into cleaning cages, etc. after unloading.

The loading/unloading of the cages into the machine is carried out semi-automatically (Figure **36**). As the cages always have the same outer dimensions, there is no need to change any settings when changing the product. This makes this type of automation extremely successful even in small series with a wide product range.

Figure 36: DLM 700-3 with semi-automation

11. Cylindrical lapping on two-wheel machines

This process wears down the material through the oblique positioning of the work pieces (lateral slippage during rotation). The precision of the load stands at < 0.2 µ in terms of circularity and straightness, while maintaining excellent surface quality. The stock removal is remarkable at 10-20 µ in approx. 10 minutes. Flawless pregrinding is also beneficial.

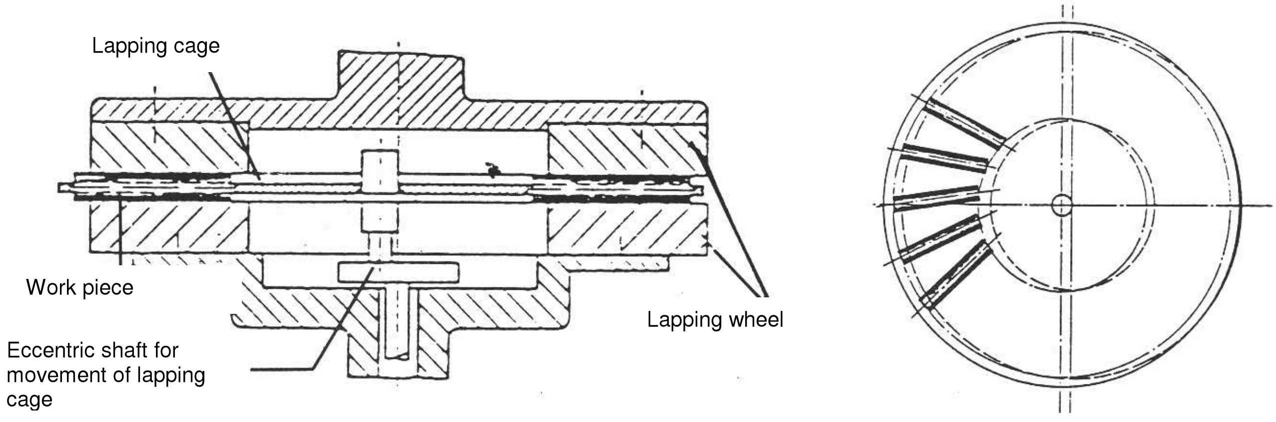


Figure 37: Work piece and a lapping-cage arrangement for cylindrical lapping

12. Comparison of single-wheel and two-wheel machines

Thanks to the excellent flexibility of single-wheel machines, this machining method is still applied nowadays. Due to the investment costs for the machine, the hourly costs of single-wheel machines are much lower, so an economic efficiency calculation must be carried out before purchasing a machine. However, it has been clearly proved that even single-wheel machines are extremely economical for machining both sides of work pieces, thanks to a simple reversing device. It is also possible to machine far more work pieces per ring. If it is possible to work with bound abrasive products, there is also a further advantage with the subsequent cleaning costs.

13. Application areas and future for two-wheel machines

In the refinishing centers of the Stähli Group, the ratio of machining orders for single- to two-wheel machines is still 2:1. However, there is a clear trend towards the more frequent use of two-wheel machines, specifically on the basis of diamond and CBN wheels.

The application areas for two-wheel lapping and flathoning machines are principally in the field of the mass machining of flat work pieces. If the machining method is coordinated perfectly, it can achieve an extremely high production rate.

New technologies, such as flathoning on fixed-grain wheels made of corundum, CBN and diamond, combined with a central and/or flood rinse and semi- or full automation have opened up a successful future for the two-wheel machine. With this method, individual work phases can be skipped, which makes the process extremely economical. “Clean lapping” or flathoning is also asserting itself for environmental reasons, and virtually all businesses are now demanding a conversion (cf. Chapter 6).

In conclusion, we would like to state that lapping/polishing and flathoning are sure of a bright future. Flathoning is being acknowledged more and more by the industry as an economical

and high-quality procedure. University studies and seminars will also contribute to this acceptance.
The company A.W. Stähli AG regularly offers its own, practical seminars. They are aimed both at beginners and operating staff at user companies. As a supplement to this document, a further document about “Lapping technology” and training and operational films in four languages are also available from the author.

14. Appendix

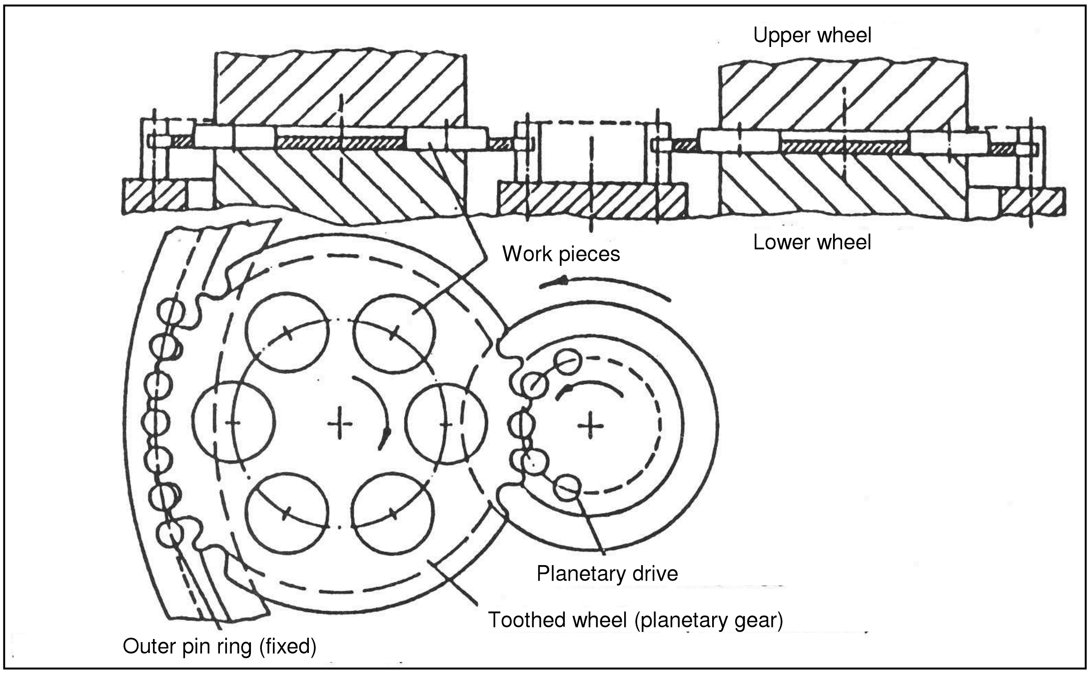


Figure 38: Planetary-drive system II

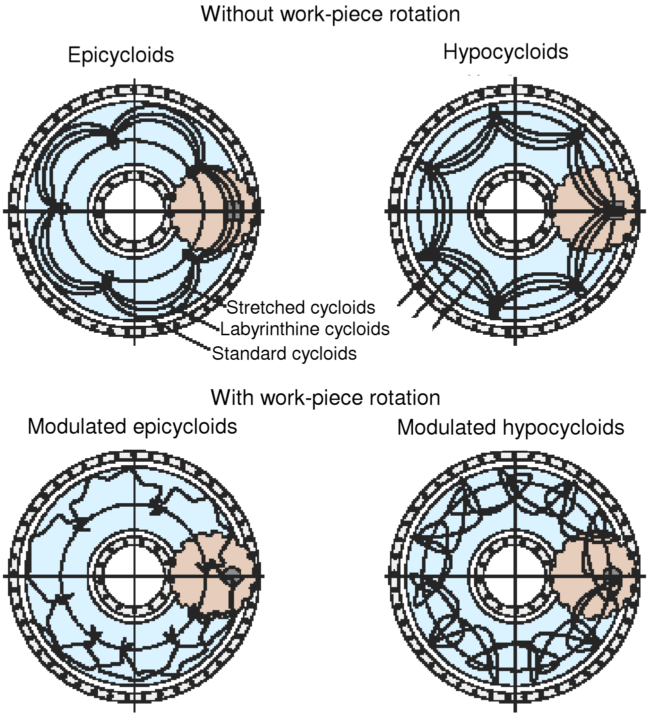


Figure 39: Machining paths of the work pieces during two-wheel machining

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