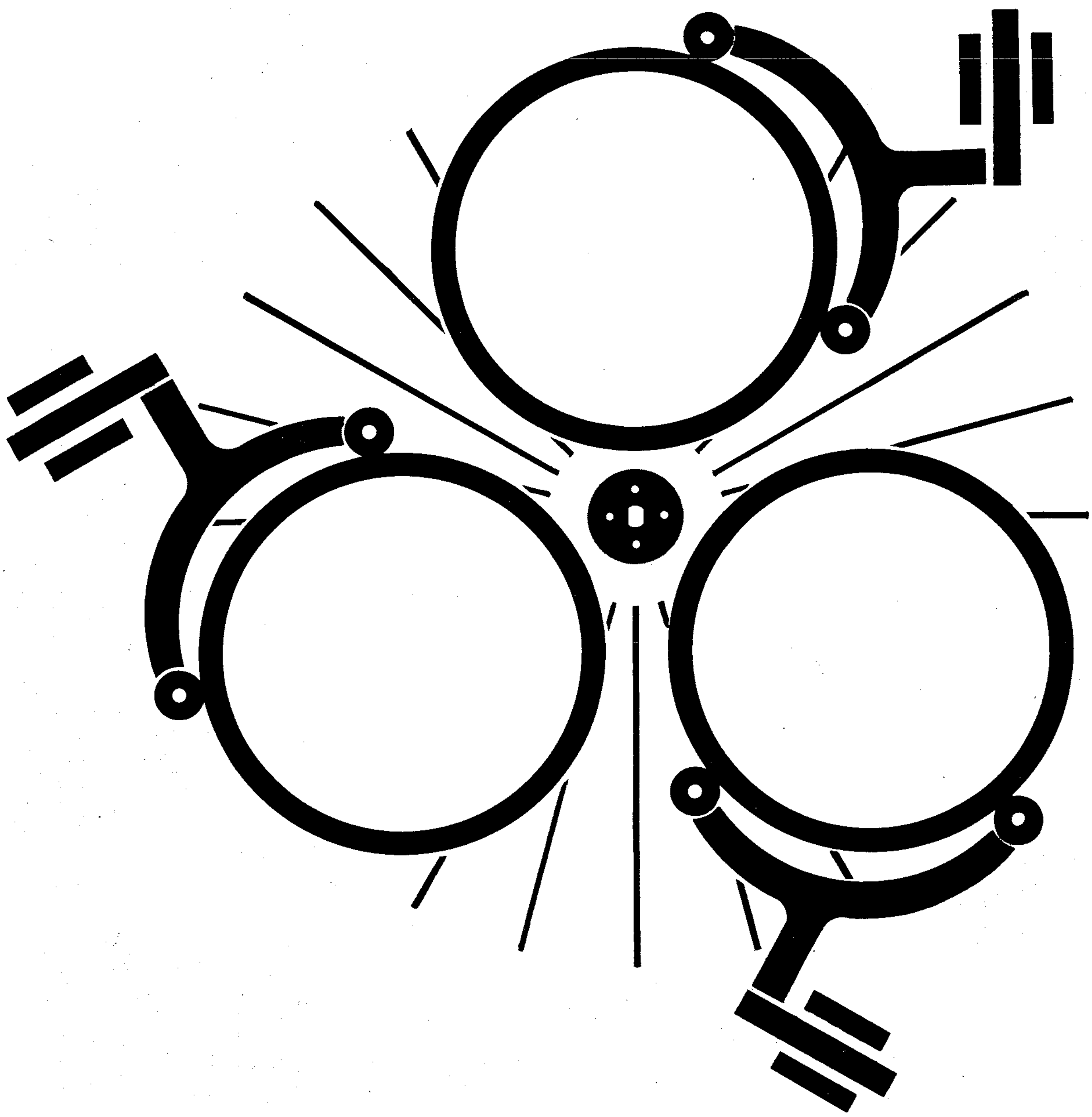
# The Technique of Lapping

by A. W. Stähli



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## T a b l e  o f  C o n t e n t s

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- A.W. Stähli AG, Pieterlen
- University of Remscheid, Prof. K. Martin, 3, 5, 6-9
- ETH Zürich, Dr. Kling, 20-27

# THE TECHNIQUE OF LAPPING*

by A. W. Stähli

Even back in the Stone Age, lapping was used as a means of fashioning tools and implements. By rotating a stick against a surface strewn with sand, our early ancestors managed to drill holes: Undoubtedly the first "machining" process ever invented. A drawing from the German Museum in Munich (Figure 1), which was produced on the basis of archaeological findings and research, shows how one of these primitive "lapping machines" might have looked.

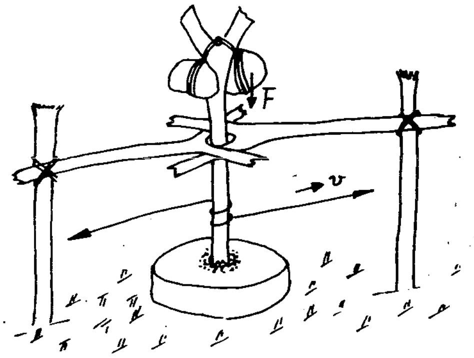



Figure 1

The drawing shows exactly the principle corresponding to the lapping process. The use of rotational friction, speed, load and the addition of sand grains and fluid result in lapping or drilling. The drawing also shows that - consciously or unconsciously - several factors already influenced the result of material removal. The material of the tool (drill), the grain (hardness and shape), the tool speed (rubbing or cutting speed), the added fluid (e.g. water) and the variable load of the tool or workpiece (surface pressure) all influenced the result.

Wood was, of course, an ideal material for carrying the sand or lapping particles, and the worker could obtain different results by choosing sand of various types and hardnesses. The work progressed more or less rapidly according to how fast the stick was rotated.

Finally, by varying the weight of the stones, the rate of material removal could be controlled - this phenomenon has only recently become properly understood.

- It can now be seen that, as a finishing process, lapping can only produce the best possible results when all other relevant factors are taken into account and fully optimised.

With the discovery of metals, casting, forging and subsequent work operations such as sharpening (bound grit particles) became primarily important, and lapping faded into disuse. It was only the introduction of gauge blocks (Johansson), and a growing demand for better quality generally, which led to a renewal of interest in the technique of lapping.

* The "Technique of Lapping" is a proprietary company term.

Unfortunately however, the makers of gauge blocks kept their knowledge of lapping secret, thus preventing this modern technology from being used in other applications. But an important step forward was made when lapping was adopted as a means of improving the possibilities available in the field of optics. Nevertheless, the widely held concept of lapping as a prohibitively expensive art form remained fully anchored, and progress towards its broader application was further hindered by the poor results obtained by hand lapping methods. Hand lapping was not only inaccurate and expensive, it was also very messy, and nobody took the trouble to study the technique in depth in order to eliminate its negative aspects.
It took the industrial efforts of the Second World War, with their enormous demands on quality, interchangeability and mass production, followed by those of the burgeoning automobile industry, to bring this technique of lapping into its own. Requirements for tightly toleranced dimensions, and for surface finish quantities that could be reliably achieved and standardised, finally gave the impetus for a breakthrough in the widespread adoption of industrial lapping.

Machine manufacturers also contributed to progress, and the single-plate lapping machine, incorporating conditioning rings for continuous correction of the lapping plate surface, was an important development. Applications became wider and more numerous, and lapping was soon a serious competitor for grinding, which had replaced it completely in some cases. The success of lapping was such that practical application jumped years ahead of research, as manufacturers preferred to press ahead with new machines rather than spend time asking and answering fundamental questions. No research centre was sufficiently interested to take up the subject, and practically no literature on lapping existed. Pioneering research was conducted by Prof. Dipl. Ing. K. Martin at the renowned Wuppertal Technical University, and it is due to the author of the present article that more recent work has been carried out at ETH, the Swiss Technical University in Zürich. Discoveries stemming from this work have now laid the foundations for further progress in lapping techniques. Several government-run research institutes have already started work in the field and verify the data from practical experience in most cases. Films and reference material are now available.
It is worth mentioning that the successes achieved in high-tech fields such as microprocessors, compact discs, computer and aerospace engineering etc. are largely based on the possibilities offered by lapping and polishing technology.

It is hoped that this article, like its predecessors, will contribute to the further success of the lapping technique by stimulating the interest of the current experts and of the new "lapping generation".
Seminars and conferences are now common and confirm that the lapping and polishing technique is now fully recognised as a modern machining method.

## The Lapping Process

In lapping, two surfaces are rubbed together with a lapping medium (lapping fluid and lapping grit) trapped between them. Material is removed by the countless loose particles between the carrier surface (lapping plate) and the workpiece pressed against it. The particles are rolled to a greater or lesser extent according to the hardness and porosity of the carrier surfaces, thus performing a kind of kneading, material-removing action on the workpiece surface. If the grit is kept from rolling, either by corresponding selection of the carrier plate, pressure or the fluid, this will cause the particles to become stuck and will lead to an extended material deformation process in a similar manner to grinding or honing. This will therefore tend to push up the material at the front or sides. For a long time it was supposed that in all cases the loose grit cut the surface. The rolling effect with its kneading action was only discovered by means of research with the electron microscope (Prof. Dipl. Ing. K. Martin). The process with bound grit particles is described in this article (also see Page 22).

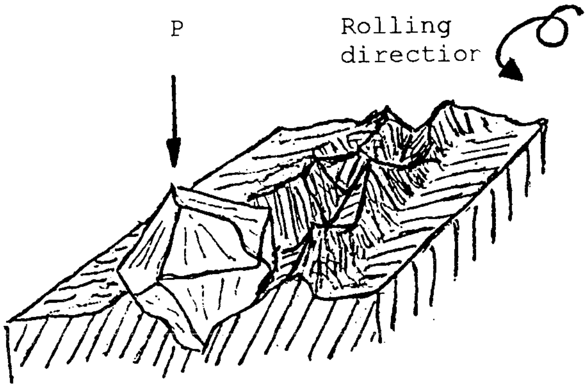



Fig. 2: Freely rolling particles

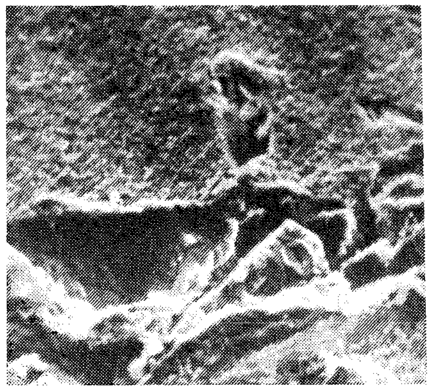


Fig. 3: Magnification approx. 3500x. Chip removal by rolling (lapping)

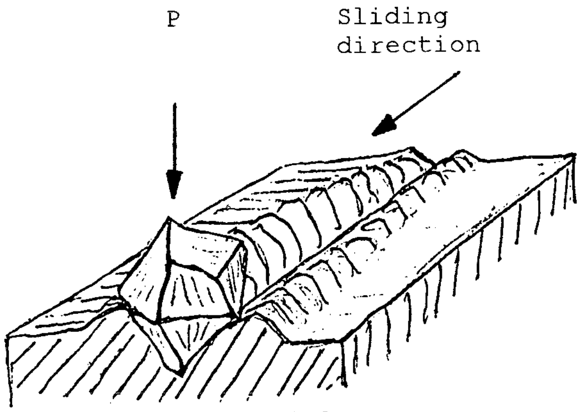



Fig. 4: Bound particles

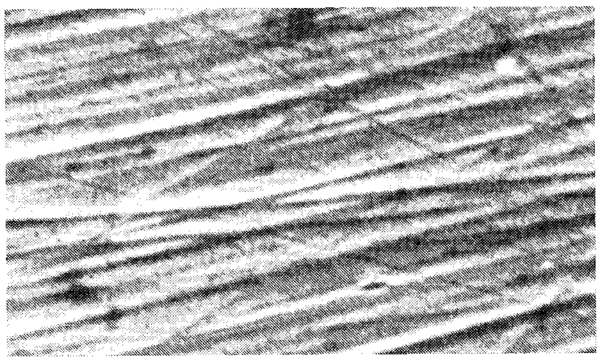


Fig. 5: Workpiece surface machined (honed) with bound grit (1350x). Material St 50, roughness Rz = 0.5 my

A simple way to observe the action of particles as illustrated above is to strew coarse lapping powder (about 150 my) on a finely lapped aluminium plate, and to cover with a scratch-free plate of perspex, which is then slid sideways slightly under a light pressure. Figure 3 shows, at high magnification, traces left by the rolling lapping particles on the fine surface. With the continuous lapping process, the continuous kneading effect causes material to break out of the machined surface, as shown in Figures 6 and 7. Figure 8 shows the result after an extended lapping time of 2 seconds with x grit particles.

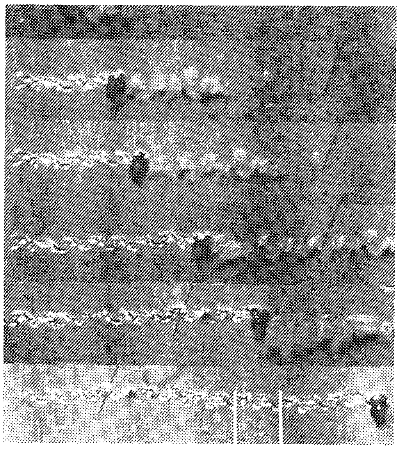


Fig. 6: Rolling process in several phases. Observe the traces (clouds) in the perspex plate.

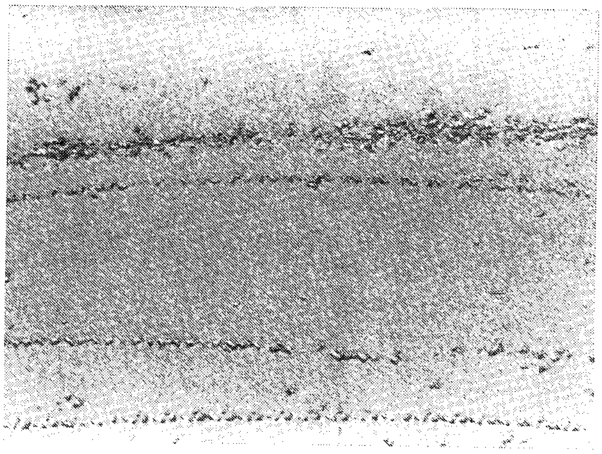


Fig. 7: A workpiece surface covered with lapping traces (12x magnification). Initial surface finely lapped, material AlMgSi, SiC lapping powder, particle size 150 my, lapping time 0.1 s

If the hardness and microstructure of the carriers or lapping plate (or carrier) are such that rolling cannot occur because the particles become stuck, as already mentioned, the result is a cutting or sliding action. Surfaces lapped by rolling appear matt (Figure 8), while pushed, cutting grit produces bright and even shiny surfaces (Figure 5). High magnifications of matt lapped surfaces show roughened material particles (Figure 9) that can, if necessary, be polished with extremely fine abrasive paper or with a polishing machine.

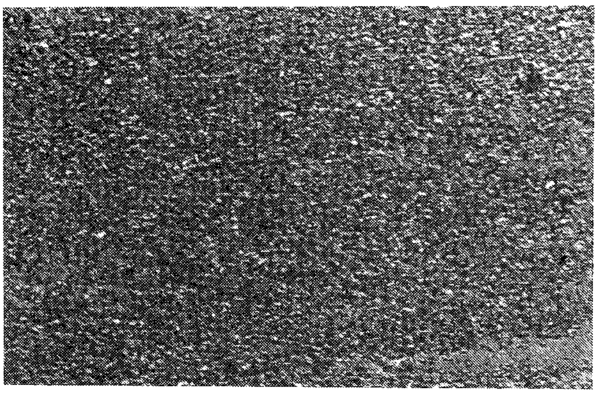


Fig. 8: Same lapped surface as in Figure 7, but after a machining time of 2 s (magnification 12x)

Fig. 9: Lapped workpiece surface (magnification approx. 2500x). Material St 50, roughness Rz = 0.8 my

Cutting generally occurs when "soft" lapping plates are used. With a soft plate and fine grit particles, a mirror finish is relatively easy to obtain, and the use of micro-particle diamond powder has allowed applications to be considerably widened.
The development of new carrier plates and their surface design, e.g. special grooves etc., as well as special fluids as a grit medium have resulted in further significant production increases during the last decade. The micro-particle diamond powder is continuing its success in grinding technology and in lapping and polishing technology.

Lapping plates or working plates can be roughly graded into 4 categories:

1. Soft working plates, e.g.: paper, cloth, felt, pitch, plastic, wood, tin, aluminium alloy, copper etc.
2. Hard working plates, e.g.: cast iron, mild steel, soft ceramic, 140-220 HB
3. Hardened working plates, e.g.: hardened cast iron, hardened steel, hard ceramic etc., up to 500 HB
4. Multi-metal plates, e.g.: combination of 2-3 different metals or sintered metal powder (see also Figure 34).

A working plate hardness value between 140 and 220 HB has been found to give optimum results. Plates with these hardness values can be continually corrected by means of conditioning rings in single-plate lapping machines, allowing high precision of the dimensional, flatness, parallelism and surface finish criteria required.
Lapping always requires a medium, which is manufactured with additives. Oil-based media are generally referred to as lapping oils or oil-soluble lapping fluids. Carriers based on water or a similar fluid are called water-based lapping fluids. The term "lapping agent" generally refers to a ready-to-use agent (product), i.e. fluid and grit.

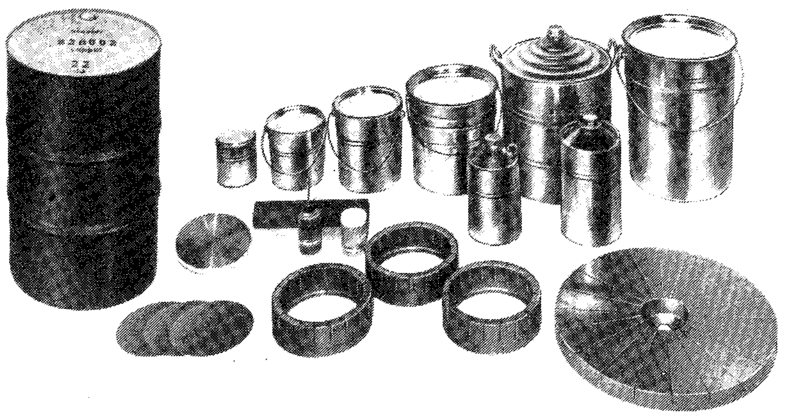


Fig. 10: Lapping agents + lapping tools

Some Figures on Lapping

The lapping process actually consists of a very large number of kneading, rolling and cutting actions. A simplified estimation would assume about 200,000 to 300,000 particles per $cm^2$, uniformly covering half the surface; a typical particle size would be about 15 my.
The lapping area on a lapping machine with a plate diameter of 750 mm is approximately 4000 $cm^2$. Assuming the above figures, about 800 million particles would be present. A rotary speed of 70 rpm results in a peripheral speed of 165 m/min, for an average velocity of 100 m/min at the outer diameter of the plate.

Fig. 11: Aluminium oxide grit 280/36 200x magnification, particle count 100%, hardly any overlapping particles.

Fig. 12: Silicon-carbide grit 800/ 6.5. 2000x magnification, particle count 150%, at least 50% overlapping grains.

Fig. 12a: Synthetic polycrystalline diamond (2-4 microns) SEM 5000x

Figure 12b: Natural diamond (2-4 microns) SEM 5000x

Assuming 100 % rolling action, lapping particles of the grain size 15 my or 47 my circumference roll 21 times per millimetre. At the average speed of 100 m/min, a rolling speed of 2.1 million revolutions per minute is possible. As all particles are not the same size and probably interfere with each other during rolling, we can assume a value of approx. 50% here, i.e. approx. 1 million revolutions per minute. At each revolution, the particle leaves three to four impressions, which results in three to four million kneading impacts per minute over a distance of 100 m. Multiplying the figure of 3 million by the number of particles involved in the lapping process at 50 % particle coverage, i.e. 400 million, results in

($3x10^6x400x10^6 = 1.2x10^{15}$) 1.2 quadrillion (1,200,000,000,000,000)

kneading impacts per minute. This figures supplies an explanation for the rapidity of material removal with lapping machines. Now, looking at grinding, , e.g. tangential grinding, it is obvious that in spite of the higher cutting speeds used, the number of active particles in action per time unit is very much less than in lapping. In addition, whereas in grinding only a portion of the workpiece surface is exposed to the wheel at any one time, in lapping the entire surface is exposed the whole time. In other words, there is no so-called "dead" time as with grinding.

## Hand Lapping

Hand lapping is now only rarely used. This method is expensive and requires a high degree of skill, and as the skilled specialists retire, companies find it difficult to obtain younger men who possess the same necessary ability. It is still suitable for one-off items, fitting work and small production series. In cases where hand lapping is indispensable, the same conditions as for mechanical lapping must be maintained. In other words, good hand lapping plates (Figure 13) and suitable lapping agents must be available.

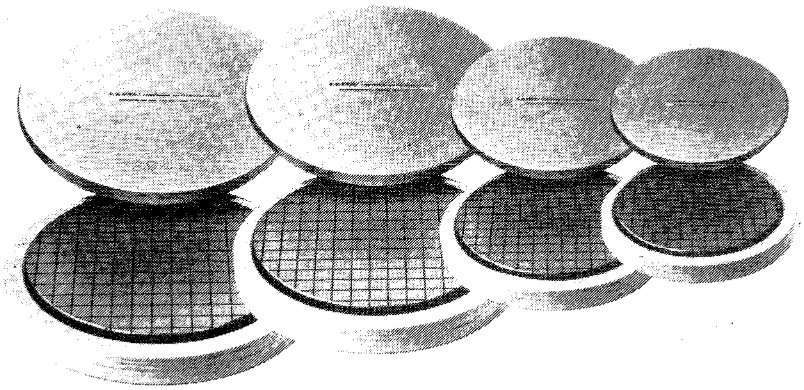


Figure 13: Hand lapping plates

Hand lapping is not an easy process. It must be realised, for example, that holding the workpieces with the fingers or with unsuitable workholders can lead to undesirable results such as uneven warming of the part, distortion, or imperfect flatness due to uneven loading of the lapping surface. Even an intermittent, stop-start action can be a source of error. Ideally, the part should be lapped with a figure-of-eight movement so as to ensure that all areas on the surface travel approximately the same distance. This type of movement requires large lapping plates. Oval movements are simpler, and are effective if the workpiece is turned several times. One problem is maintaining the plate flatness. Lapping plates should be re-ground, or better still machine-lapped, from time to time. This can be performed by the plate manufacturer. It is common practice to give the plates a slightly convex form in order to counter the usual heavier wear in the middle.

The most important requirement in hand lapping is that the lapping-oil film should be saturated evenly with grit particles. If this lapping film contains too much abraded material, it becomes black and resinous in most cases. A rule of thumb is that when lapping with the intention of removing material, the movement should be light and even; for polishing, more pressure can be applied. More frequent cleaning of the lapping surface and inspection of the process produce the best results.


A bench lapping machine with a working plate diameter of 300 mm was developed as an interesting intermediate solution (Figure 14). This machine allows both manual and machine lapping. The difference is that the working plate (lapping plate) rotates, while the workpiece is moved to-and-fro across the surface. The process is considerably simplified, and results of high to very high quality, comparable to those given by larger machines, can be obtained.

Figure 14:
Bench-type lapping machine for hand lapping and machine lapping, equipped with lapping medium pump, variable distribution head, variable-speed drive and timer.

## The single-plate lapping machine

The single-plate lapping machine is finding a wide and ever-increasing range of applications, and for this reason a detailed description of this machine and its working principles and applications will now be given.

As in all machining processes, the operations are all conducted with specific objectives, in order to maintain control over the different factors influencing the quality. These factors are four in number:

1. The flatness of the lapped surface is theoretically a copy of the lapping plate, which is constantly kept flat by the conditioning rings.
2. The parallelism and dimensional uniformity of workpieces is ensured by the flatness of the pressure plate and by interchanging the workpieces.
3. The size accuracy is achieved by the precisely controlled removal rate per unit of lapping time.
4. The surface finish is determined by the grit type, lapping fluid (film) and pressure.

In modern lapping machines, the material removal rate is high enough to make lapping a serious competitor to grinding in many cases. In contrast to grinding, the same grit and the same lapping medium can be used for a wide range of materials.
The fixtures used for lapping are generally simple to make, and therefore inexpensive. Nowadays, workpieces are commonly delivered for finishing with a machining allowance of 0.2 to 0.5 mm, so lapping can be implemented directly after turning, milling, punching or sintering, except in the case of large-area, solid workpieces, as these workpieces require longer machining times (large chip volume). Components with large recesses, such as covers, housings, flanges with recesses or holes, rings etc. are often provided with large machining allowances, and in such cases lapping is frequently much faster than grinding. There is no "grinding in air", as the entire workpiece surface is machined at the same time.

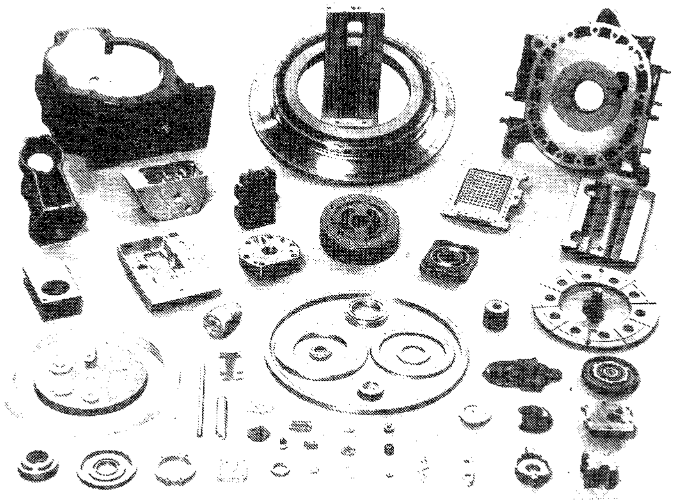


Figure 15:
Assortment of workpieces machined on a single-plate lapping machine. However, relatively tall workpieces and workpieces with complicated shapes can also be machined.

The main factor contributing to the success of the single-plate lapping machine (Figure 16) is the effect of the conditioning rings, which keep the lapping-plate surface flat during the lapping process. The single-plate lapping machine is in fact the only machine tool in general use which is capable of continuous self-correction for maintenance, or even improvement, of operating accuracy. The accuracy of all other machine tools decreases with each second of use unless the errors are compensated or corrected by means of additional equipment or measuring controls (it is worthwhile to make cost comparisons).

## Conditioning Rings and Functional Principle

The first feature noticed on a single-plate lapping machine is the rotating working plate, which carries the 3 or 4 conditioning rings. These conditioning rings are guided by roller forks in most cases and rotate with the plate (Figure 16).

How the conditioning rings are driven depends on the friction force in the outer ring circle. This variable is surface, speed and pressure-dependent; it is in the same direction as the working plate. At the inner diameter of the working plate, the area proportion is significantly lower and the friction force acts in the opposite direction. The difference between these two friction forces therefore determines the direction of rotation and the torque, or rotational speed, of the conditioning rings. In practice, the speed of the conditioning rings is approximately the same as that of the working plate. It is important to note that the speed of rotation of the conditioning rings, in addition to their weight, has a considerable influence on the effect the conditioning rings have on the shape of the lapping plate. The heavier the conditioning rings and the larger their surface, the better is the conditioning effect.

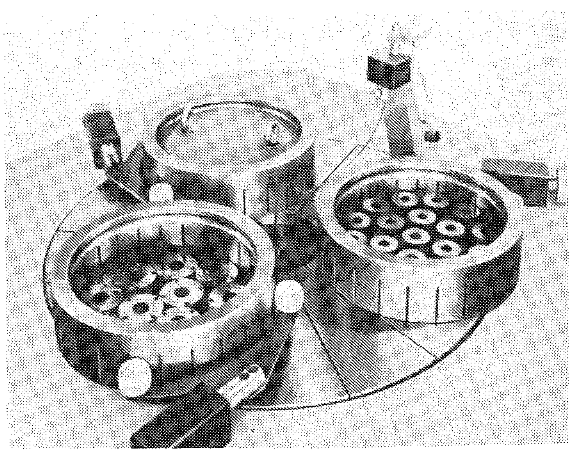
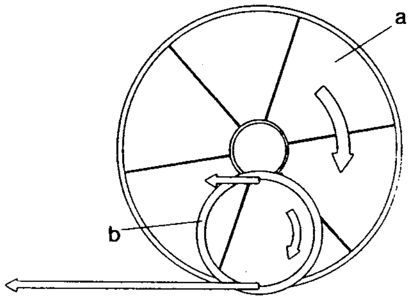


Figure 16:
Single-plate lapping machine with three conditioning rings

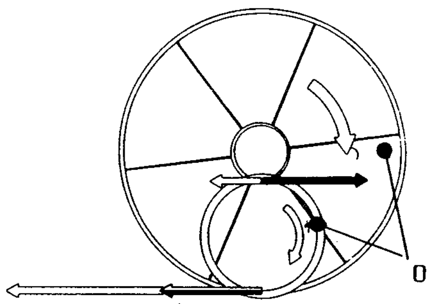
If it is assumed that the lapping plate and the ring rotate at a 1:1 speed ratio, the material removal rate (travel distance) will be identical at each point on the conditioning ring. The process is illustrated by Figures 17, 18 and 19.




The assumption of a 1:1 speed ratio between the working plate and ring is in fact confirmed in practice.

a = Working plate
b = Conditioning ring

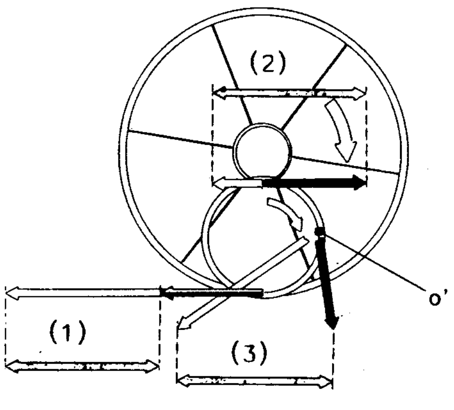
Figure 17: Working plate with one ring




The working plate and the conditioning ring each possess their own peripheral speeds and specific travel distances.

To understand how the conditioning rings keep the working plate flat, it is necessary to grasp that it is the difference in travel distance between the point on the plate and point on the ring (0) that gives the grit particles the opportunity to perform work.

Figure 18: Travel distance difference




The same direction and speed of rotation now results in the following picture:
At the outer diameter of the plate, the two travel distances are covered in the same direction and are subtracted to form the working distance (1).
At the inner diameter, by contrast, the two travel distances are covered in opposing directions, and the travel distance, ring point to plate point, is added to form the working distance (2). This is clearly shown by the diagram: The working distances are exactly the same at the outer and the inner plate points.

Figure 19: Comparison of travel distances

Assuming a randomly selected point o', the specific distances are not only horizontal with respect to the selected point, but also at a certain angle. In other words, at a certain angle with respect to the conditioning ring and working plate.

Nevertheless, the working distance (3) always remains constant, irrespective of the selected point. However, a constant working distance also means that the material removal rate will always be the same at the corresponding radius. The working distance is reduced correspondingly if the radius is smaller. The working distance decreases to the mean working-plate travel distance at the centre of the conditioning ring. It is advantageous not to locate workpieces at the center of the conditioning ring. This is possible if templates are used.

According to with studies by Dr. Jochen Kling, formerly of ETH Zürich, Figures 17-19 represent a simplified case. The speed ratio Lambda (conditioning ring : working plate) is 1:1 here. At this ratio, the relative speed between the conditioning ring and working plate, or between the workpiece and working plate, is uniform for every point in the ring. This is not the case for other speed ratios; the speed may even become zero. This can necessitate independently driven conditioning rings, but the cost and complexity of the additional mechanism are usually prohibitive.

It is interesting to compare the path described by a point on the ring or on the workpiece across the working plate. This is a cycloid of a shape depending on the speed ratio and workpiece radius. Figures 20-27 show paths of this kind, with the speed of the conditioning rings being compared with that of the working plate. The ratio Lambda "+" indicates identical directions of rotation, and Lambda "-" indicates opposite directions of rotation with respect to the working plate.

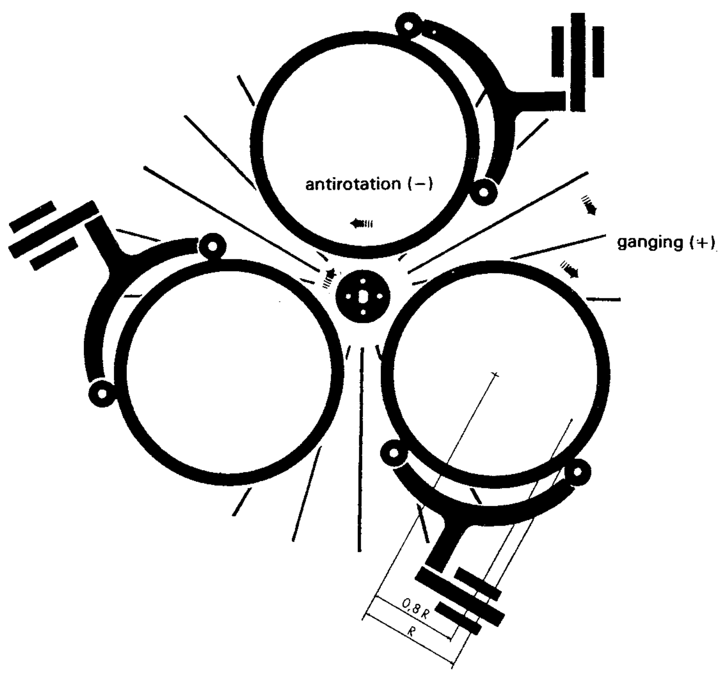



Figure 19a:
Working plate with three conditioning rings

The drawings of Figures 20 to 27 were for a workpiece radius of 0.8 x distance "ring center - ring edge".

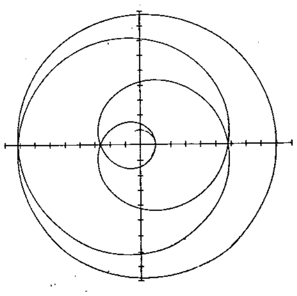


Figure 20:
Lambda = + 0.25
Conditioning ring rotating at 25% of plate speed, in the same direction

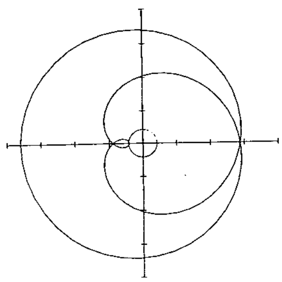


Figure 21:
Lambda = + 0.5
Conditioning ring rotating at 50% of plate speed, in the same direction

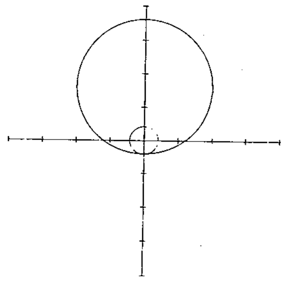


Figure 22:
Lambda = + 1
Conditioning ring rotating at the same speed and in the same direction

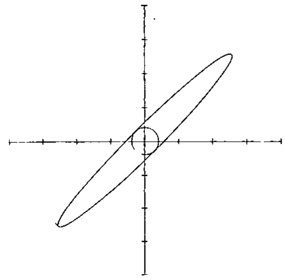


Figure 23:
Lambda = + 2
Conditioning ring rotating at 2x the plate speed, in the same direction

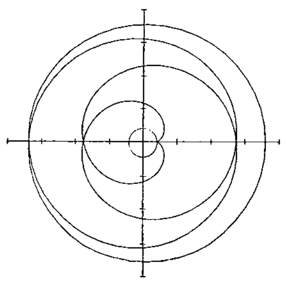


Figure 24:
Lambda = - 0.25
Conditioning ring rotating at 25% of the plate speed, in the opposite direction

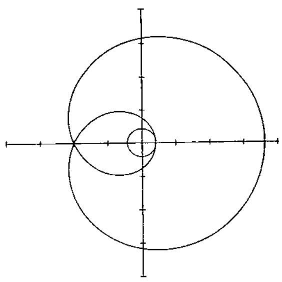


Figure 25:
Lambda = - 0.5
Conditioning ring rotating at 50% of the plate speed, in the opposite direction

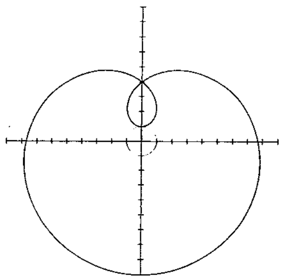


Figure 26:
Lambda = - 1
Conditioning ring and plate rotating at the same speed and in the opposite direction

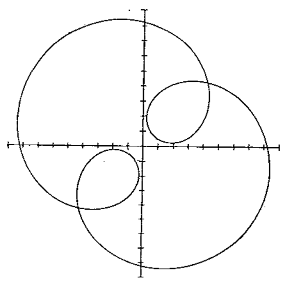


Figure 27:
Lambda = - 2
Conditioning ring rotating at 2x the plate speed, in the opposite direction

The cycloid paths can be considered as thin strips of material removed from the working plate surface by the particles positioned at the ring or workpiece point. The darker areas in Figures 28 and 29 are a measure of the path density and thus of the material removal at a certain plate radius. It is thus clear how the plate shapes can be influenced by selecting the right speed ratio of the conditioning rings. In simplified form, it can be said that more material removal results in the inner area of the working plate if the conditioning rings rotate in the same direction as the working plate (Figure 29). If the conditioning rings rotate in the opposite direction, this results in increased material removal in the outer area of the working plate (Figure 28). Figures 28 and 29 show the path of a point on the conditioning ring or workpiece across the working plate.

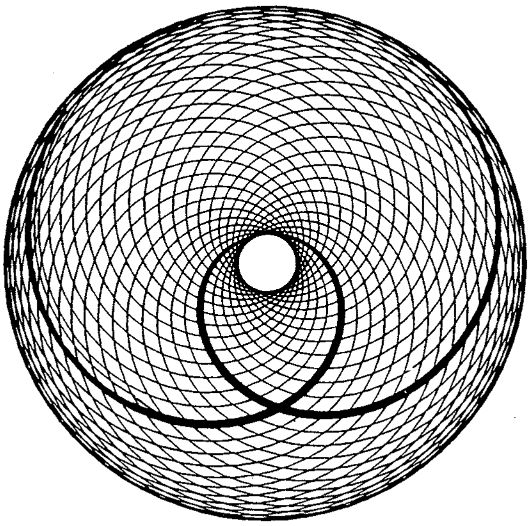


Figure 28: Lambda approx. - 0.5
(Figure 25)

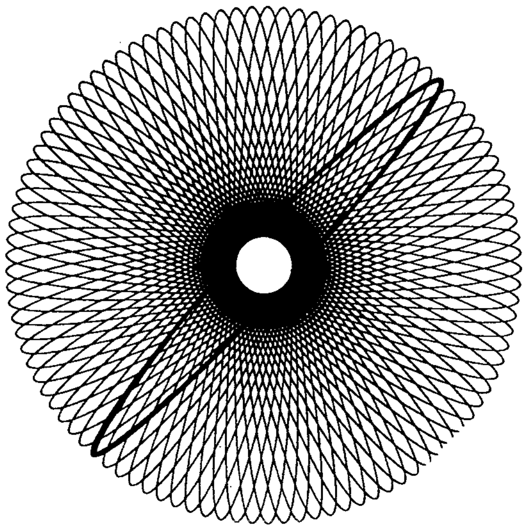


Figure 29: Lambda approx. + 2
(Figure 23)

The conditioning rings therefore should not rotate with a lambda value greater than 1 (speed equal to the working plate) in order to ensure optimum flatness correction. This is mostly the case in practice, except if the flatness error between the inner diameter and outer diameter is large.

The following flatness errors can result from excessive wear on the working plate by the workpieces:

1. Concave working surface
2. Convex working surface
3. Axial run-out in the working surface

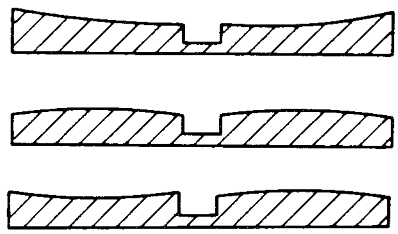


Figure 30: Flatness errors

Error 1a: The concave error in most cases results from too many workpieces in the center of the conditioning ring.

Remedy: Use templates and do not locate parts in the center.
Increase intrinsic weight of the conditioning rings.

Error 1b: A concave error can also occur if the pressure plate (load plate) is no longer flat.

Remedy: Give the pressure plate a slightly concave shape by lapping it on a slightly convex working plate (use central adjustment facility, also refer to Page 16 "The working plate" and Page 17 "Pressure plates").

Early detection of an incipient error is important. For this purpose, measuring straight edges with several dial gauges distributed over the entire working plate, are necessary (Figure 31). The errors, and the corresponding correction measures, must be entered in a table (Figure 32). This entry is indispensable, particularly in the case of shift changes.

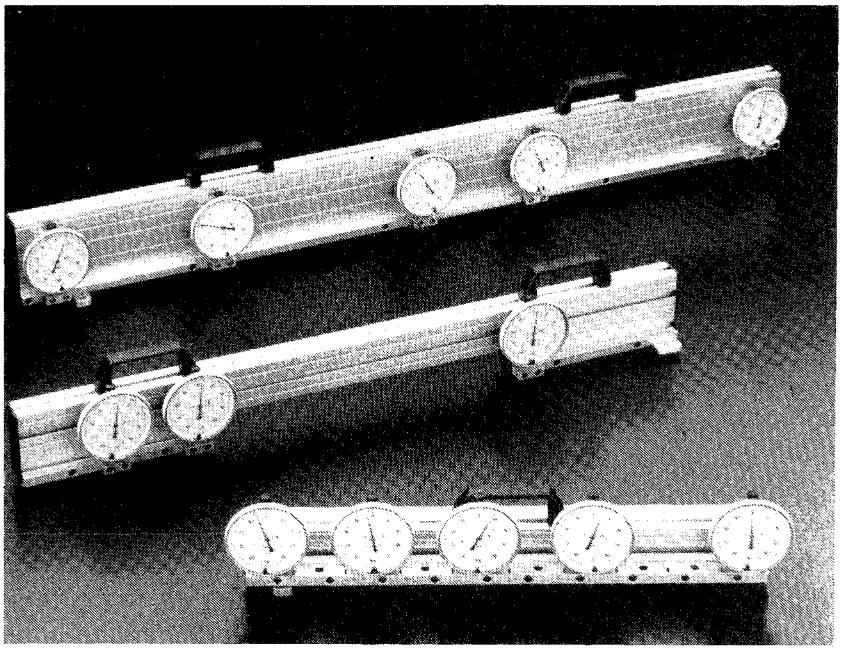
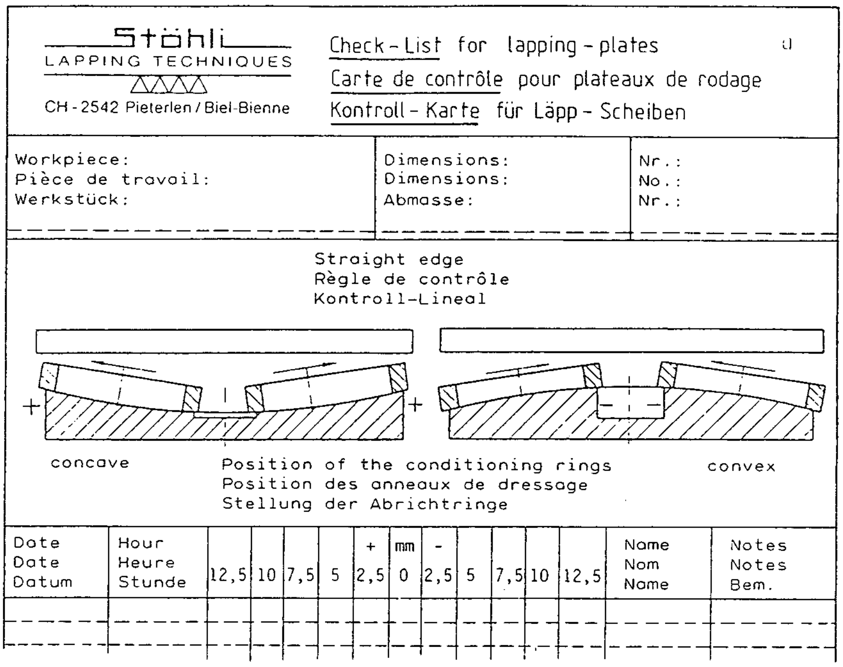


Figure 31:
Measuring straight edges



Stähli
LAPPING TECHNIQUES
CH-2542 Pieterlen / Biel-Bienne

Check-List for lapping-plates
Carte de contrôle pour plateaux de rodage
Kontroll-Karte für Läpp-Scheiben

| Workpiece:<br>Pièce de travail:<br>Werkstück: | Dimensions:<br>Dimensions:<br>Abmasse: | Nr.:<br>No.:<br>Nr.: |
|---|---|---|

Straight edge
Règle de contrôle
Kontroll-Lineal



Position of the conditioning rings
Position des anneaux de dressage
Stellung der Abrichtringe

| Date<br>Date<br>Datum | Hour<br>Heure<br>Stunde | 12,5 | 10 | 7,5 | 5 | + 2,5 | mm 0 | - 2,5 | 5 | 7,5 | 10 | 12,5 | Name<br>Nom<br>Name | Notes<br>Notes<br>Bem. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |

Figure 32:
Checklist for conditioning-ring adjustment in steps of 2.5 mm

Error 2: The convex error can be caused by excessive adjustment of the conditioning rings, which is far less likely. This error can also occur if one conditioning ring is located far out and the others far in on the working plate.

Remedy: Move conditioning rings to center position, load several workpieces in the centre of the workpiece holder, load the conditioning rings and lap until the convex error is corrected. Regularly inspect the working plate and check the correction (Figures 31, 32 and 69).

Error 3: The axial run-out error takes a relatively long time to manifest itself. It may be caused by uneven hardness or microstructure areas in the working plate. However, even an irregularity in the base plate can cause the error. Frequently, the cause is that the base plate and working plate are firmly bolted together, and so-called distortion errors result in the event of temperature fluctuations. Cooled working plates offer a decisive advantage here. With this error, the conditioning rings "ride" as if on a roller-coaster. The same thing naturally also happens with the workpieces. Errors of this type cause long machining times and uneven flatness of the workpieces.

Remedy: If the axial run-out is too large, correction with the conditioning rings will be difficult. The error can be reduced slowly by lowering the support rollers and using a conditioning ring that is at least 33% larger. Workpieces of various sizes should be lapped at the same time. If necessary, a special conditioning plate with a diameter of at least half of the working-plate diameter (it can even extend beyond the center) can be used. Lapping agents should be added to the free area of the working plate. The working plate should be turned on a lathe if the error is too large.

The conditioning ring guide system is provided with a shifting mechanism which, by moving the ring in or out, causes a slight difference in the speed ratio. If the conditioning ring overhangs the inside or outside edge of the working plate, the specific contact pressure increases, and this results in greater material removal.

- Convex working plate: Shift rings towards the center (Figure 69).
- Concave working plate: Shift rings towards the outside (Figure 69).

The conditioning rings and the working plate constitute the most important part of the machine (Figure 16). They fulfill a range of functions:
- Accommodating the workpieces
- Rotating the workpieces during lapping
- Constant conditioning of the working plate during production
- Spreading the lapping medium to a thin film, with uniformly distributed grit particles to ensure perfect seating of the workpiece on the working plate and therefore a perfectly flat surface. The flatness of the lapping plate is copied onto the workpiece.
- Removing the abraded material either into the slots provided in the plate for this purpose, or via the edge of the plate if it is not slotted
- Dissipating heat to the air
- Guiding the workholder, the intermediate layer and the pressure plate (Figure 33).

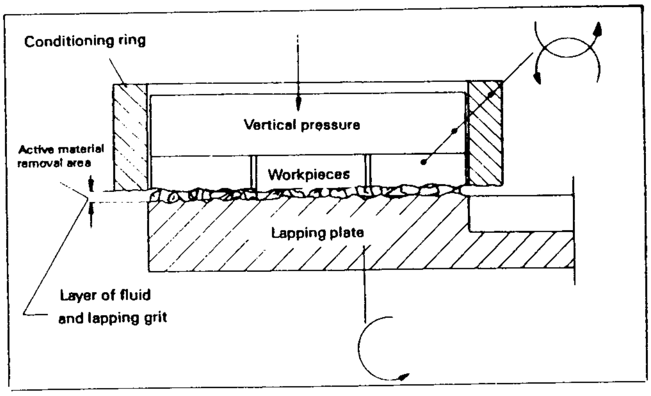



Figure 33: Schematic drawing of a lapping process.

## The working plate

The usual material for the working plate is gray cast iron, hardened by a special method to the required value.The structure should be fine-grained, and free of blow-holes.
For lap-polishing, especially when using diamond grit, plates of steel, copper, zinc, aluminum or even wood are used. Working plates of pitch, plastic, fabrics or coated films are used for ultra-fine polishing.
Today, all the crucial parts of a lapping machine can be designed for optimal mutual efficiency. If minimum wear is required for example, the working plate can be made of sufficient hardness, but in view of the ease with which continuous reconditioning can be performed, soft to medium-hard plates are most often used, and these have the additional advantage of being cheaper than harder plates.
Once a lapping plate acquires an imperfect profile (convex, concave lapping surface), correction takes a long time. Some machines are fitted with a device for rapid shape correction, consisting of a means of slightly distorting the plate during use. Residual errors are then compensated for by moving the conditioning rings to the appropriate position as described earlier.
Practise shows that a slightly convex working plate can give good results in a short time in certain cases, for example when lapping parts with large surfaces. The rapid form correction device is useful in such applications as well.

The working plates are usually provided with radial slots to drain the used lapping medium off the surface. Unslotted plates are best small, irregular workpieces, or when lapping carbide metal or ceramics using water-based media with a high grit content. Lapping or polishing with diamond powder requires a surface profile similar to a V-thread, flat thread or taper thread. Plastic, fabric or felt films are bonded on base working plates. They are good carriers in terms of structure in most cases, but require frequent cleaning or replacement.

New multi-metal working plates are a combination of 2-3 different materials. They are available as spiral inserts, in mosaic or round form. The first type has the advantage of continuous material removal as the workpieces pass over the plate, as well as additional grooves. The multi-metal working plates are much more expensive and are suitable for use with diamond lapping agents. The conditioning rings must be matched correspondingly.

Further working plates with fixed grains (lapping powders of all types, mixed with binding agent, baked or fired) open up new possibilities.

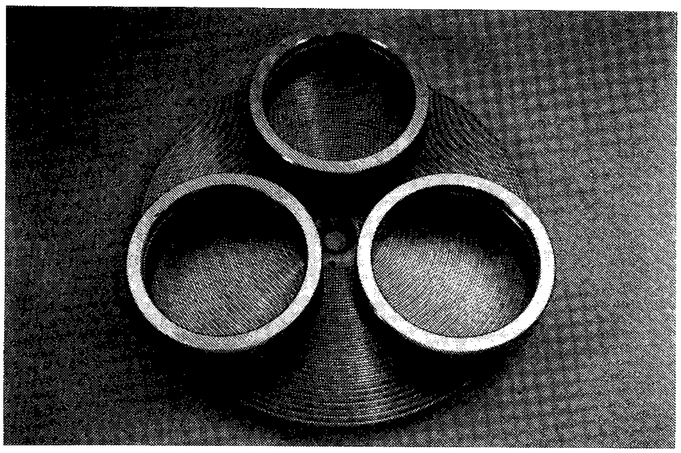


Figure 34:
AWS multi-metal plate with various metals as spiral inserts.

In this context, we would like to point out that water-based fluids are also suitable for this purpose. This prepares the way for "clean lapping". Environmental protection will also play an important part in micromachining technology in future.

## Pressure Plates

Pressure plates are also an important part of the lapping process, performing the following functions:

- Pressing uneven or rough workpieces against the lapping plate (felt or rubber pads).
- Obtaining acceptable parallelism of the top and bottom faces of the parts by means of the perfectly flat bottom of the pressure plates without pads.

For parallelism, the contact surface of the pressure plate should be perfectly clean, and the lapping fluid should be uncontaminated and form a uniform film. It is also advantageous to interchange the workpieces diagonally from time to time.
Cast iron, steel or aluminum are suitable as materials. Aluminum has proven to be suitable in the case of frequent handling. However, additional pneumatic loading is required in this case to permit economical work.

## Workholders

When lapping small batches, the workpieces are guided in so-called workholders. These are plastic, aluminum or steel plates that are the same size as the inside diameter of the conditioning ring, and are provided with openings slightly larger than the workpieces. They serve to hold the workpieces in a constant position, preventing them from mutual collision and yet allowing diagonal interchange. Depending on the weight and size of the parts, parallelism tolerances within 0.002 mm can be achieved in this way. It is advantageous to bond liners on the workholders in order to prevent the lapping agent from being wiped off by the workholders lying flat on the working plate.

## Speed of the Working Plates

The rate of material removal is largely proportional to the rotational speed, or to the distance covered per unit of time. The maximum rotational speed is limited due to the centrifugal force occurring. At high speeds, the lapping fluid gets thrown outwards, and relatively high, narrow workpieces undergo a wobbling motion that is detrimental to flatness and parallelism. High speeds are by no means a disadvantage for the actual lapping process. However, it remains to be seen whether a rolling process of the lapping grain can still take place (also see Pages 3 + 4). Most practical experience seems to indicate that this is not possible. Scratching traces on the workpiece surface indicate more of a "honing" process, i.e. the working plates would require ring-shaped or cross grooves to prevent the lapping agent from being thrown off. Working plates with bound grit permit higher speeds, if this is possible with the material in question.
Newer designs of lapping machines incorporate a soft-start facility or stepless speed control of the working plates, step-controlled pressure loading, cooled working plates, digital time measurement and automatic loading, turning, unloading systems etc. as the minimum equipment complement (Figure 43).

## Machine Types

A single-plate lapping machine is logically identified according to the lapping-plate diameter. The FLM 300 (Figure 14) has a lapping-wheel diameter of 300 mm, for example. Machines with plate diameters of 300 mm to approx. 2000 mm are available. Special sizes range up to 3000 mm. Some manufacturers also specify the number of rings (Figure 36) or the intended purpose of the machine (FLM 750-P = polishing machine).

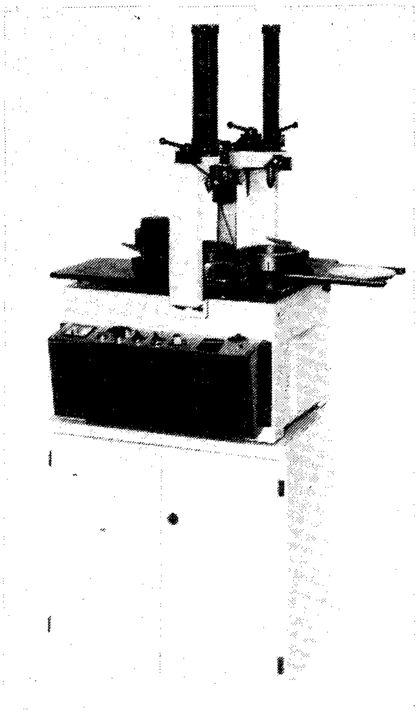


Figure 35:
Single-plate
lapping machine
FLM-400

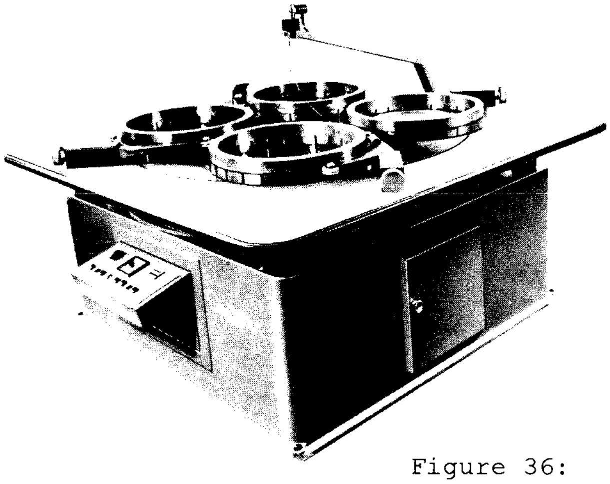


Figure 36:
Single-plate
lapping machine
ML-1500-4R

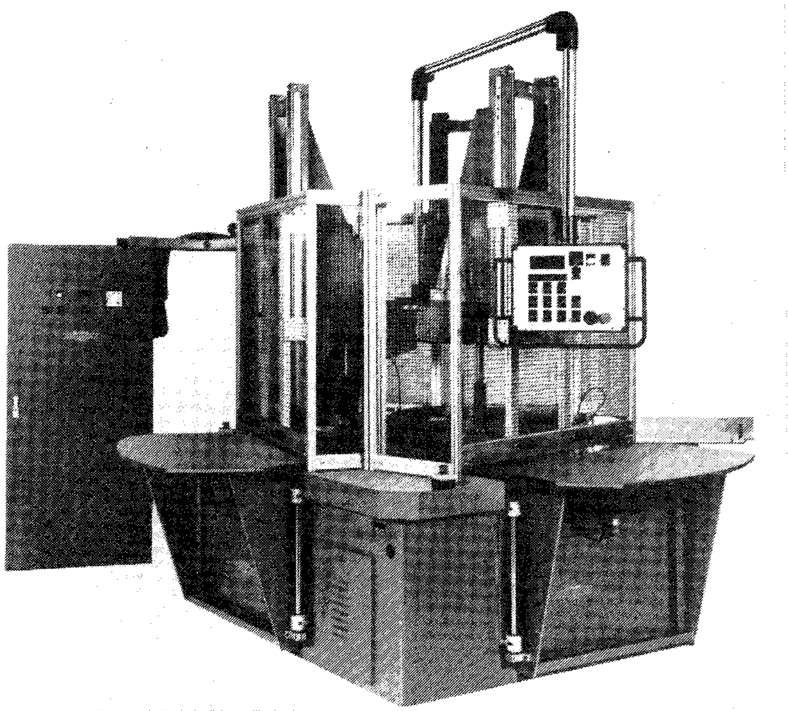


Figure 37:
High-volume production
lapping machine FLM 1250-HT with cycle system

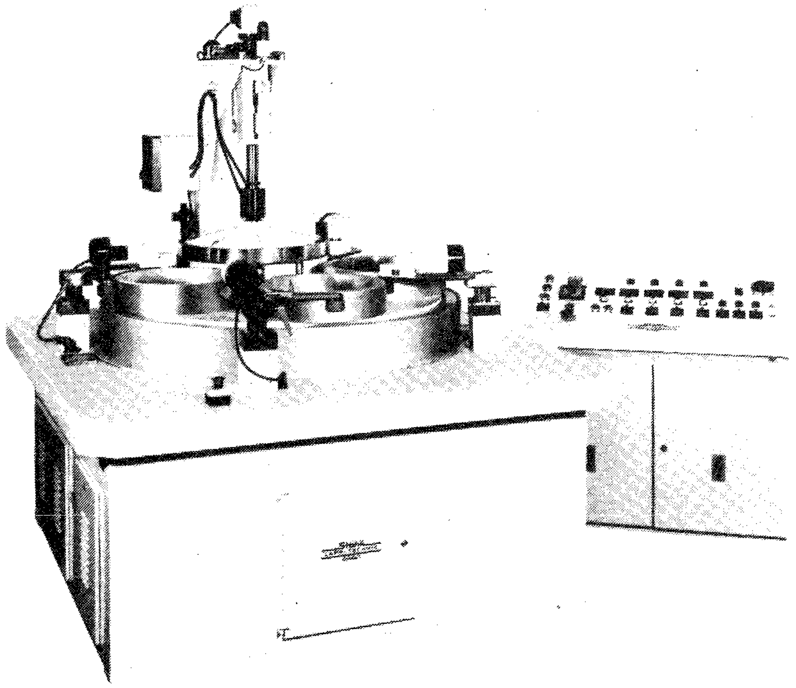


Figure 38:
Optical polishing machine
FLM 1200-P

Many machines can be equipped with special attachments to change the type of lapping method. For example, an additional lapping plate and a drive can be provided to convert the basic machine to a cylindrical lapping machine or a dual-plate machine (Figures 39 and 40).

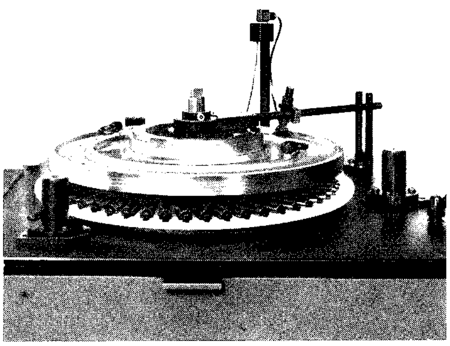


Figure 39: Conversion to a cylindrical lapping machine, type FLM 500-R

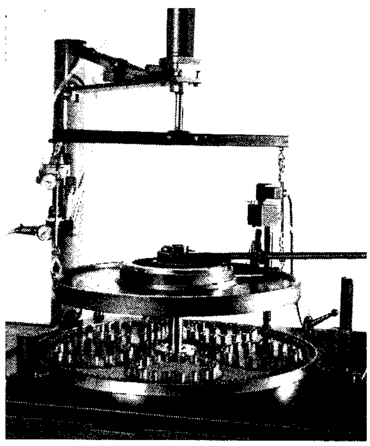


Figure 40: Conversion to a dual-plate lapping machine, type FLM 500-2P

Many lapping machines have been converted to extremely productive machines with additional equipment. The main condition for this is a strong basic design with adequate drive power. A cooling system is indispensable here.

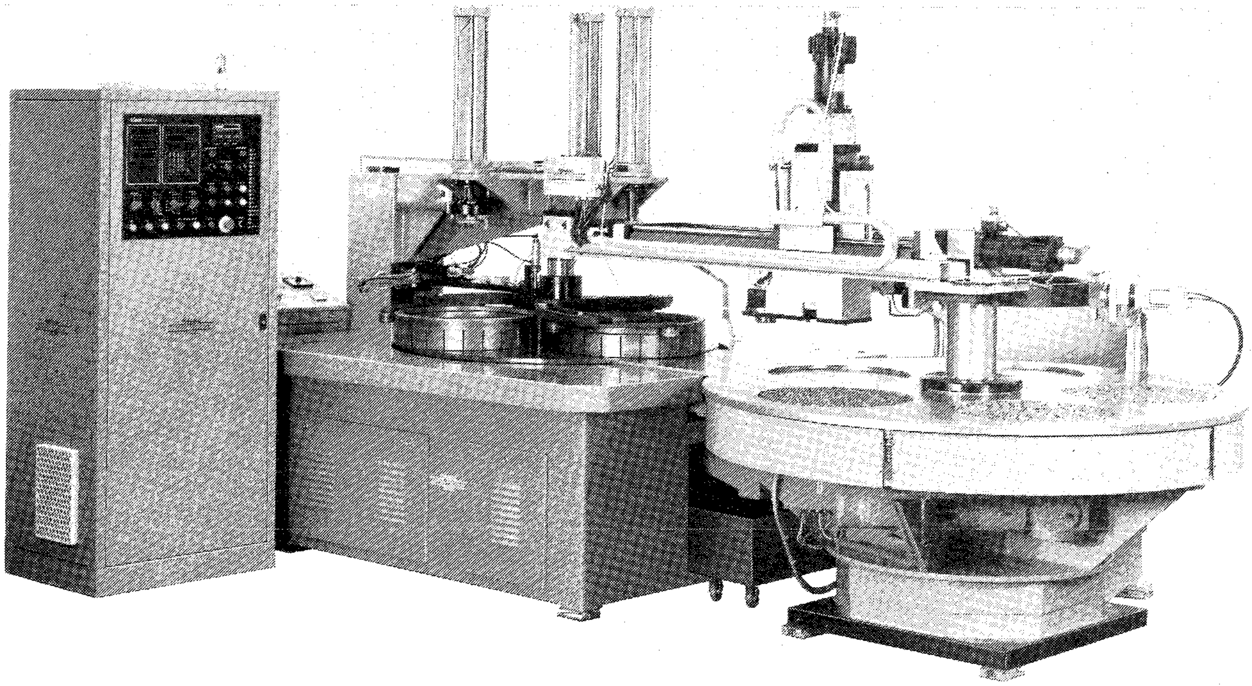


Figure 41: FLM 1250-CNC, fully automatic lapping machine with numeric control

Automation of a lapping and polishing machine can eliminate some "dirty" work. New types of fluid, which are based on water in most cases, and bound working plates offer new possibilities. These include clean, reflective surfaces similar to those achieved with honing or grinding (also see top of Page 17, "Clean lapping").

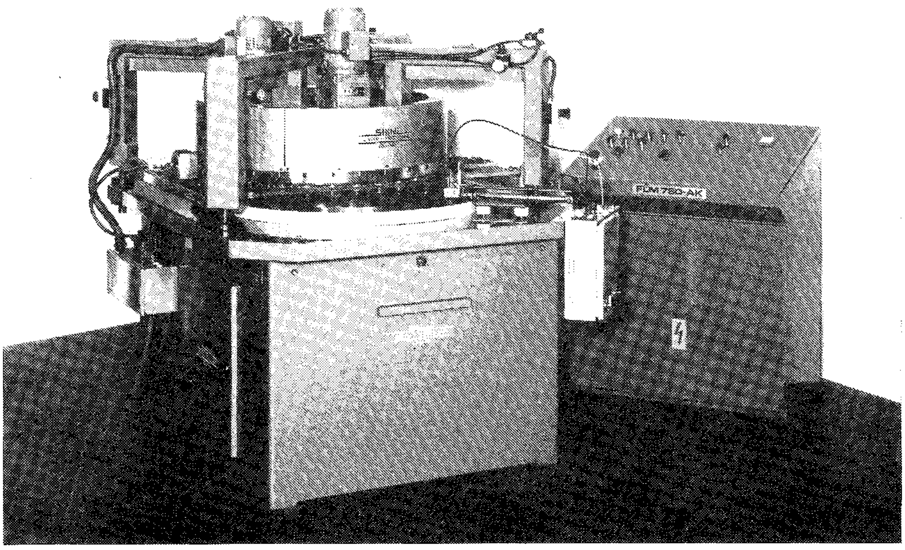


Figure 42: FLM 750-AK, fully automatic polishing machine with loading and unloading system, steplessly controlled turntable with 24 rotating spindles. During 1-3 minutes of operation, 10 spindles with workpieces are constantly active on the polishing disc. Unit times of 6-18 seconds are achieved.

## Centerless Cylindrical Lapping

What is centerless cylindrical lapping?

It is a simple-to-use finishing method for round parts, permitting narrow tolerances, exact fits and excellent surface finish quality. The use of centerless cylindrical lapping machines makes lapping rings or lapping stones unnecessary and produces superior quality in the shortest possible time.

As delivered ground for lapping or polishing, the parts comprise an allowance of 4-8 microns according to the surface roughness. The roundness can be improved somewhat by lapping. Best results are achieved with a pressing finger which has approximately the same radius as the workpiece.

The smaller drive roller turns the workpiece. The larger working or lapping roller removes material by means of a path or speed difference at the contact line (Figure 43).

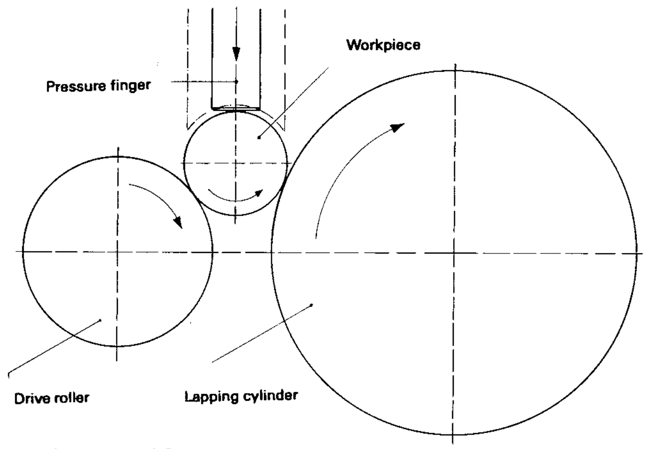



Figure 43:
Schematic of cylindrical lapping with pressing finger

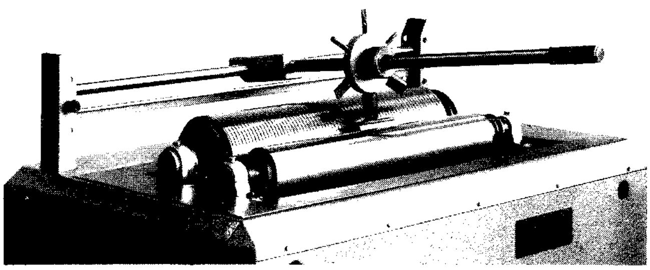


Figure 44a:
Centerless cylindrical lapping machine CLM 500

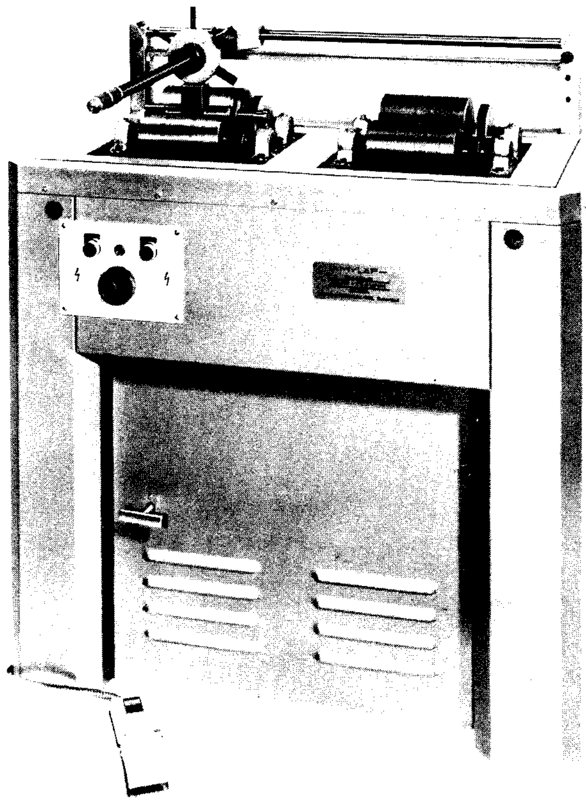


Figure 44:
Centerless cylindrical lapping with the machine CLM 150-2

Special machines for diamond lapping, diamond polishing or chemical polishing already involve drive power values of 8-15 kW and pressure loads up to 5000 N per ring for a plate diameter of 500 mm.

Fully automatic machines with computer numeric control of the various processes have been available since the beginning of the 80's. Wear is compensated for automatically, and mass-produced parts can be manufactured at very low costs.

## The lapping oil

The fluid used in the lapping medium must be chosen carefully. If the fluid (e.g. oil) is too viscous, the film formed is very thick, and if the particles are too small, their tips protrude insufficiently from the film. If the film is too thin, it may rupture and allow metal-to-metal contact between the working plate and the workpiece. An excessively greasy medium is inefficient. Abraded material therefore must be removed from the lapping area immediately. (This is comparable to the flow of swarf during machining.)
Rule-of-thumb: Large lapping grains - thick medium film
Small lapping grains - thin medium film

Wrong or untested fluids can lead to great time and quality losses. Inadequate or irregular rotation of the conditioning rings due to incorrect lapping agents has serious consequences for the correction effect on the working plate (also see Page 8-15).

## The Lapping Powder

The lapping powder comes in the form of silicon carbide, aluminum oxide, boron carbide, diamond powder (also see Page 38 "Lapping with Diamond") or similar products. The quality criteria are the particle size, size distribution, hardness, shape and number of edges.
The particle size is chosen according to the surface finish required, and naturally also according to the rate of material removal judged necessary. Of the lapping grits classified in Figure 45, the most common are sizes 400, 500 and 600. Many types of grit are commercially available, the most effective for giving a good surface finish being those with the least variation in size. This is particularly the case for fine grit and slurried grit. For any given grit size the maximum variation should not exceed 20% of the nominal. Oversized particles cause scratching, and undersize ones are simply carried along with the mass, without doing any useful work.

A scratch on the workpiece surface can cost many times the saving made by preferring a poor-quality lapping medium to a higher-quality one. The powder should mix easily with the fluid, forming no lumps and remaining suspended for a considerable time before settling, and should contain no water (if mixed with oil bases). Slow settling is important to avoid separation before the medium is pumped into the lapping zone. Mixing ratios range from 1:10 to 1:5 or from 100 to 200 g powder to 1 liter of fluid. When using water and anti-corrosion additives, and lapping over the entire plate, the ratio can be as high as 1:3 to 1:2 or approx. 300 to 500 g per liter. when changing from one grain size to another, it is recommended to rinse the working area thoroughly at least.

A change from conventional grains to diamond grains has become apparent in the field of lapping (also see Pages 38-40 "Lapping with Diamond"). The use of new, suitable lapping fluids is opening up more and more new lapping possibilities. Even soft materials are being lapped successfully with diamond. New types of working plates and their surface design allow use of this machining method without significant extra costs per workpiece. Diamond powder, which is still expensive, frequently results in shorter machining times and cleaner surfaces.

Virtually every grit particle is used in an optimum manner when lapping with diamond. This is the only explanation why, by comparison with conventional lapping, the same or even better machining performance can be obtained with so few grains. A comparison of consumption for machines of average size (diameter 700-1000 mm) resulted in the following values on the basis of lapping oil:

- With diamond lapping, the consumption is 224 Carats or 0.4-0.8 g/h
- With conventional lapping with Si-C, the consumption is 200-1000 g/h

With water-based lapping fluids, the consumption increases to 5 times this amount, or 1000-5000 g/h. The consumption ratio "diamond:Si-C" therefore is 1:5000, which initially seems unbelievable.

Let us now briefly consider the grain count:

1 Carat, i.e. 0.2 g diamond powder with a mean particle size of 15 microns, contains approximately 3 million particles or 15 million particles/g (according to Spring).

1 g Si-C 500 with a mean particle size of 13 microns contains 10 - 15 million particles/g or approximately 10-15 billion particles/1000 g (10,-15,000,000,000). This is an incomprehensibly large number in most cases. This quantity is exceeded x-fold with smaller particle sizes.

The utilization of conventional grit (Si-C, $Al_2O_3$ etc.) is therefore relatively poor.

It can be concluded from this that many particles are not used on the working plate or break so easily that rolling does not take place (also see Page 1-4 by Martin and the author). There is much work for research and development here.

It is already known that with water-based lapping, the majority of the particles are required for establishing a grit layer instead of an oil film. The rounding of the workpiece edges also tends to confirm this (according to Prof. Spur and Dr. Sabotka, Ceramic Machining).

Lapping powder classifications in accordance with FEPA Standard

| Designation Particle count | Average particle size (50% value) | 94% value min. | 3% value max. |
|---|---|---|---|
| F 230/53 | 53.0 | 34 | 82 |
| F 240/45 | 44.5 | 28 | 70 |
| F 280/37 | 36.5 | 22 | 59 |
| F 320/29 | 29.2 | 16.5 | 49 |
| F 360/23 | 22.8 | 12 | 40 |
| F 400/17 | 17.3 | 8 | 32 |
| F 500/13 | 12.8 | 5 | 25 |
| F 600/9 | 9.3 | 3 | 19 |
| F 800/7 | 6.5 | 2 | 14 |
| F 1000/5 | 4.5 | 1 | 10 |
| F 1200/3 | 3.0 | 1 | 7 |

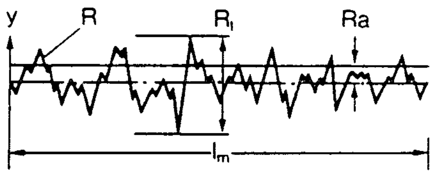
Figure 45: Table of lapping grits in accordance with FEPA Standard

## Surface Finish Quality

With a given grit size and fluid viscosity, varying the lapping pressure produces a higher or lower material removal rate, a thicker or thinner film, and a rougher or finer surface finish. In practice, therefore, pressure is usually kept light at the beginning of the process, increased as work proceeds, and diminished towards the end. This results in the optimum material removal rate, surface finish and flatness.

As an example, on a steel part hardened to 60 HRc, lapped using silicon carbide 500 grit, a pressure of 250 g/cm$^2$ will produce a surface finish of about Ra = 0.2 my (N4) or Rz 0.6-0.8, whereas by reducing the pressure to 50 g/cm$^2$ a surface finish of about Ra = 0.05 my (N2) or Rz 0.2-0.3 can be obtained.

The international surface finish standards (DIN 4762, 4768, ISO 4287/1-2. 4288) are applied in an analogous manner, in that the surface finish quality is specified in Ra values or in the even more accurate Rt values. In practice, the more realistic value Rz is also specified, which is determined by averaging 5 separately measured Rt values. Suitable measuring equipment for acquiring these values is now commercially available (Figure 54).




$$R_a = \frac{1}{l_m} \int_0^{l_m} |y| \, dx$$

Figure 46:
Arithmetic mean roughness value Ra

The mean roughness value Ra (DIN 4768) is the arithmetic mean from all values of the roughness profile R within the measuring distance $l_m$. It therefore specifies the average deviation of this surface profile from the mean line.

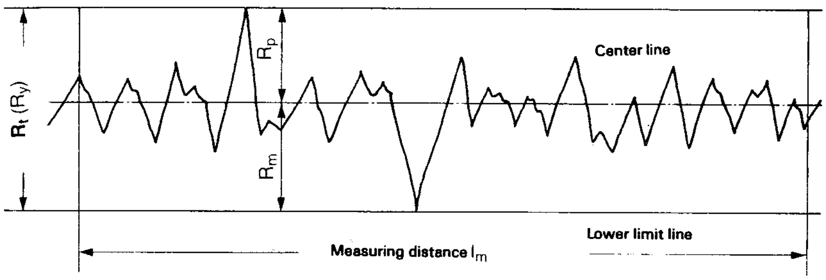
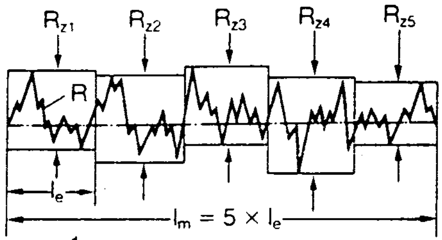



Figure 47:
Maximum peak-to-valley height Rt

The maximum peak-to-valley height Rt (DIN 4748) is the vertical distance between the highest and lowest points of the roughness profile R within the overall measuring distance $l_m$. In other words, this is the height difference between the highest mountain and lowest valley within the measured range.




$$R_z = \frac{1}{5}(R_{z1} + R_{z2} + R_{z3} + R_{z4} + R_{z5})$$

Figure 48:
Mean roughness depth Rz

The <u>mean roughness depth Rz</u> (DIN 4768) is the average value from the individual roughness depths of five individual measuring distances $l_e$ in sequence. In other words, it is calculated from five Rt values.

| N-class (Swiss VSM) | Ra value my (m) | Ra value my (inch) | Approx. comparison Rt | Approx. comparison Rz | Symbols (old system) |
|---|---|---|---|---|---|
| N 1 | 0.025 | 1 | 0.12 | 0.10 | |
| N 2 | 0.05 | 2 | 0.3 | 0.25 | |
| N 3 | 0.1 | 4 | 0.6 | 0.5 | |
| N 4 | 0.2 | 8 | 1.0 | 0.8 | |
| N 5 | 0.4 | 16 | 1.8 | 1.6 | |
| N 6 | 0.8 | 32 | 3.6 | 3.15 | |
| N 7 | 1.6 | 63 | 7.2 | 6.3 | |
| N 8 | 3.2 | 125 | 14.5 | 12.5 | |
| N 9 | 6.3 | 250 | 30 | 25 | |
| N 10 | 12.5 | 500 | 60 | 50 | |
| N 11 | 25 | 1000 | 120 | 100 | |
| N 12 | 50 | 2000 | 250 | 160 | |

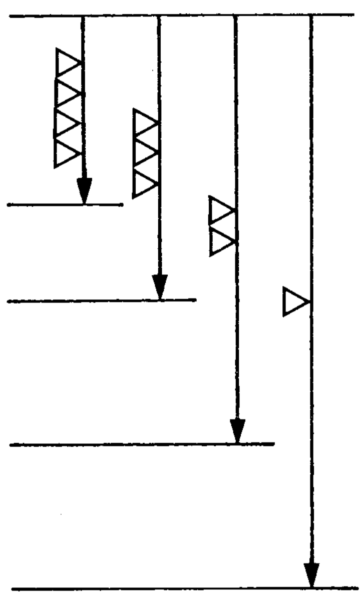


Figure 49: Roughness standards table (N Standard), arranged for comparative reading according to A. W. Stähli and DIN 4768/1

Surface roughness designation systems

| Rt/max µm | CLA µm | CLA µ" | RMS µm | RMS µ" | ex CCCP class | CCCP µm Rt |
|---|---|---|---|---|---|---|
| 0.06 | 0.02 | 0.75 | 0.02 | 0.8 | 14 | 0.06 - 0.12 |
| 0.1 | 0.03 | 1.2 | 0.04 | 1.3 | 13 | 0.06 - 0.12 |
| 0.2 | 0.06 | 2.5 | 0.08 | 2.8 | 12 | 0.12 - 0.25 |
| 0.3 | 0.09 | 3.7 | 0.10 | 4.2 | 11 | 0.25 - 0.50 |
| 0.4 | 0.13 | 5.0 | 0.14 | 5.6 | | |
| 0.5 | 0.16 | 6.7 | 0.18 | 6.9 | | |
| 0.6 | 0.19 | 7.5 | 0.21 | 8.3 | 10 | 0.5 - 0.80 |
| 0.7 | 0.22 | 8.7 | 0.25 | 9.7 | | |
| 0.8 | 0.25 | 10.0 | 0.28 | 11.1 | | |
| 0.9 | 0.28 | 11.2 | 0.32 | 12.5 | | |
| 1.0 | 0.31 | 12.5 | 0.35 | 14.0 | | |
| 1.2 | 0.38 | 15.8 | 0.42 | 16.7 | 9 | 0.8 - 1.60 |
| 1.5 | 0.47 | 18.8 | 0.53 | 20.9 | | |
| 1.8 | 0.57 | 22.6 | 0.64 | 25.5 | | |
| 2.0 | 0.64 | 25.1 | 0.78 | 27.9 | 8 | 1.6 - 3.20 |
| 2.4 | 0.73 | 30.1 | 0.85 | 33.4 | | |
| 2.8 | 0.89 | 35.2 | 0.99 | 39.0 | | |
| 3.0 | 0.95 | 37.6 | 1.06 | 41.9 | | |
| 3.5 | 1.11 | 43.9 | 1.24 | 48.8 | | |
| 4.0 | 1.27 | 50.2 | 1.41 | 55.8 | 7 | 3.2 - 6.30 |
| 5.0 | 1.59 | 62.7 | 1.77 | 69.7 | | |
| 6.0 | 1.91 | 75.5 | 2.12 | 83.6 | | |
| 7.0 | 2.22 | 87.5 | 2.48 | 92.6 | | |
| 8.0 | 2.54 | 100.0 | 2.83 | 111.7 | 6 | 6.3 - 10.00 |
| 10.0 | 3.18 | 125.5 | 3.54 | 140.0 | | |
| 20.0 | 6.40 | 251.0 | 7.80 | 279.0 | 5 | 10.0 - 20.00 |
| 40.0 | 12.70 | 502.0 | 14.10 | 558.0 | 4 | 20.0 - 40.00 |
| 60.0 | 19.10 | 755.0 | 21.20 | 836.0 | 3 | 40.0 - 63.00 |
| 125.0 | 39.50 | 1560.0 | 43.50 | 1750.0 | 2 | 63.0 - 125.00 |
| 200.0 | 64.00 | 2510.0 | 78.00 | 2790.0 | 1 | 125.0 - 200.00 |

1 µm = 0.001 mm = 39.37 µ"    1 µ = 0.000'001" = 0.025'4 mm

Figure 50: Machine manufacturers' comparison table

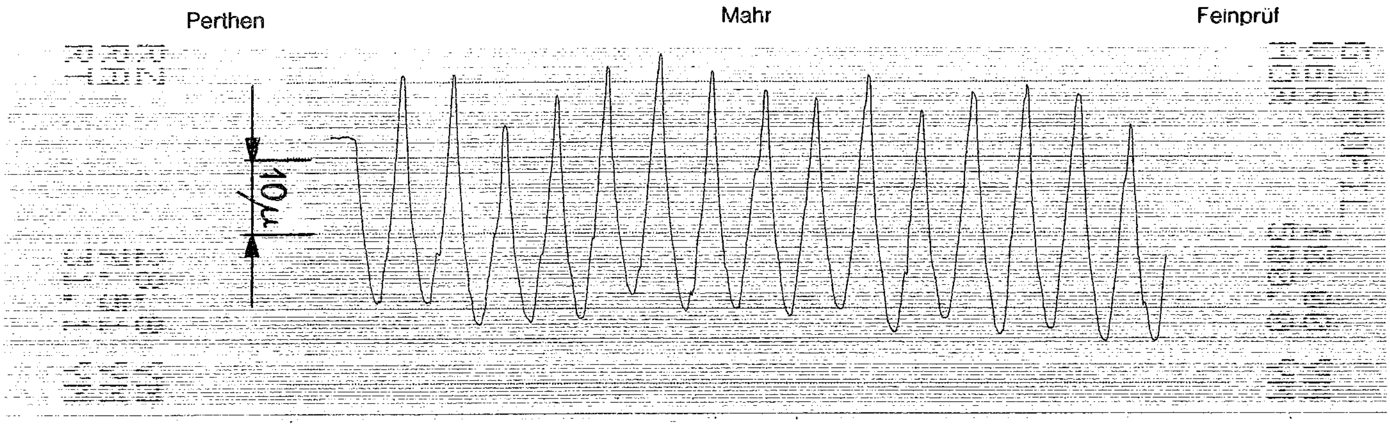



Figure 51: Surface profile of a turned workpiece of steel.
Ra 7.51, Rt 31.1

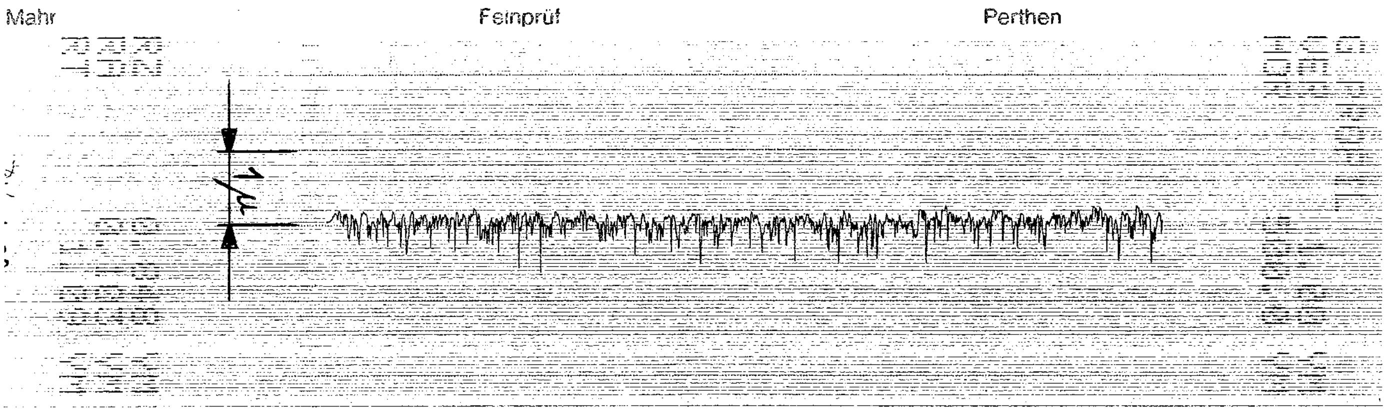



Figure 52: Same surface as in Figure 51 after lapping with Si-C 500 grain, but vertical scale increased 10 x. Ra 0.103, Rt 1.09.

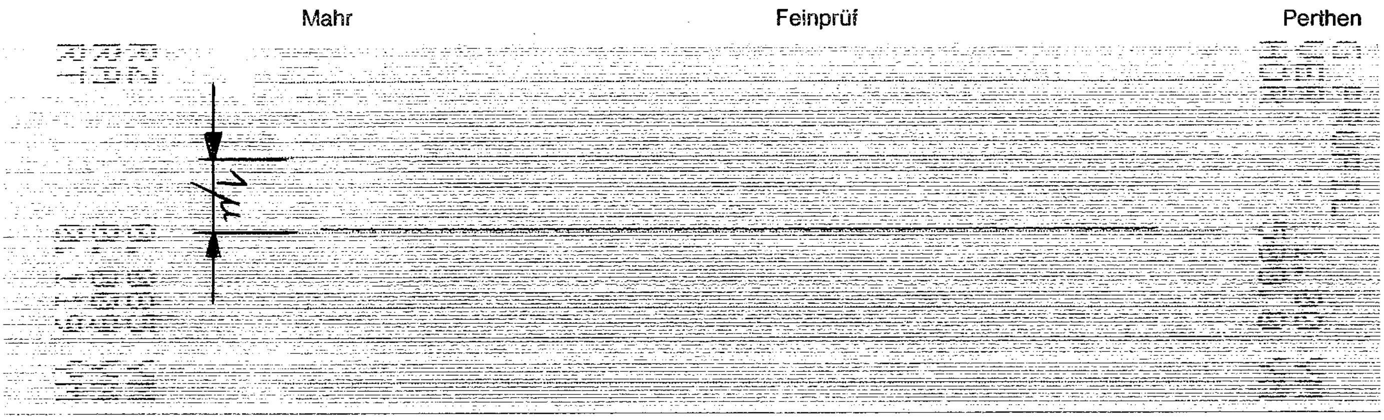



Figure 53: Same surface lapped with diamond 2-3 my, same magnification as in Figure 52: Ra 0.009, Rt 0.119

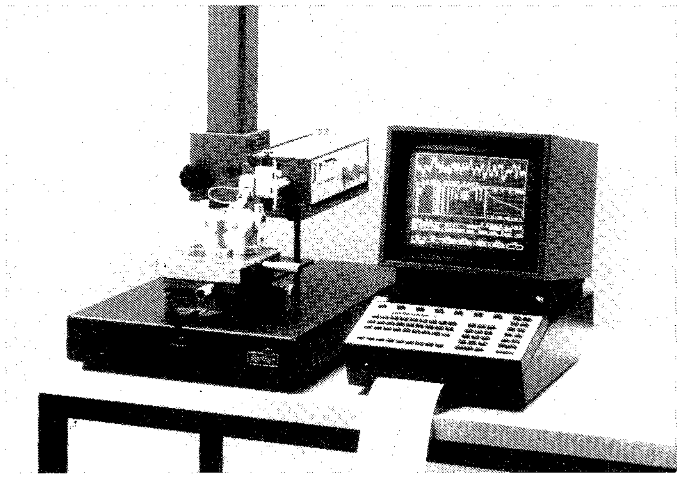


Figure 54:
Roughness measuring unit with multiple evaluation

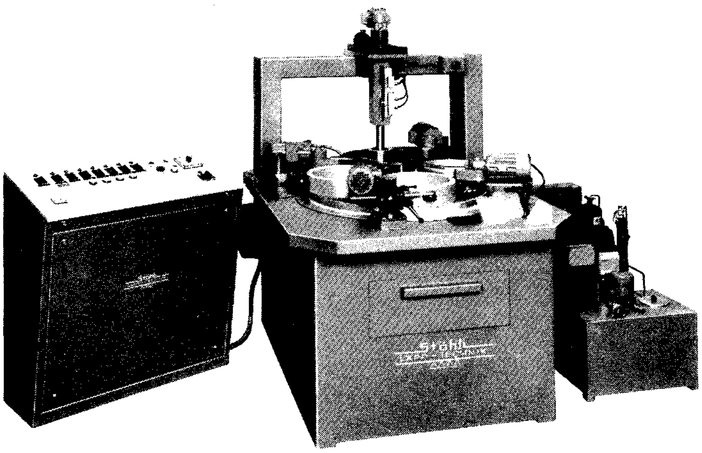


Figure 55:
Optical polishing machine FLM 750-P with cooling unit

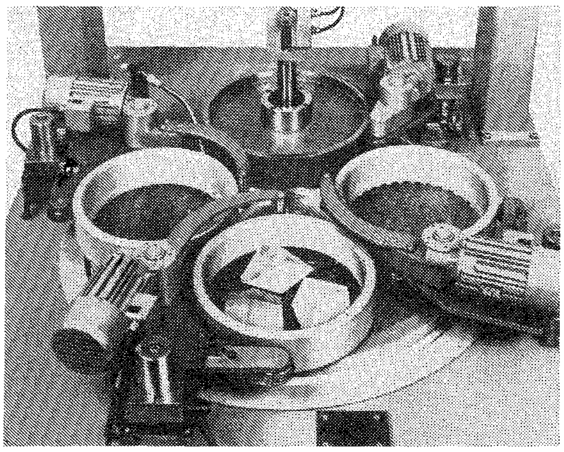
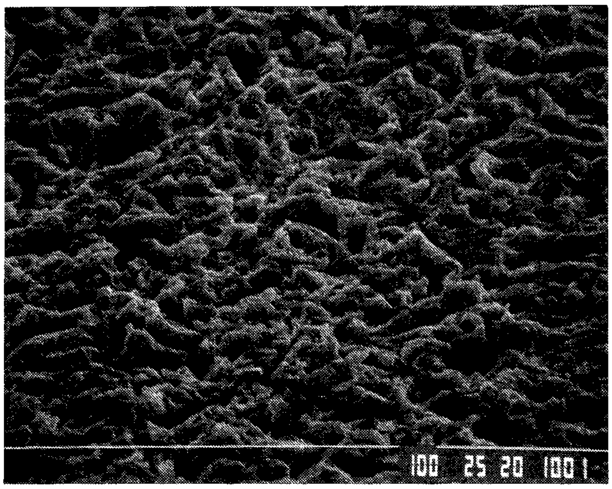


Figure 56:
Close-up view of FLM 750-P optical polishing machine

Many of the electronic measuring instruments in use today for determining surface finish quality are equipped with microprocessor control systems and printers (Figure 54). However, the true value of the results obtained is open to dispute, as most are only approximate, and vary according to the device concerned. It is essential to compare the type of probe (radius), needle pressure, measuring distance and filtering (cut-off), see DIN Standard 4768. It is also very important to consider the material of the workpiece, its microstructure, hardness and type of machining, as well as the direction of the measuring distance with respect to the machining traces. Even when applied with a pressure of only 1 mN, a diamond probe with a radius of 5 microns will compress the surface of a non-ferrous part to about 50% of the roughness depth.
The porosity of the microstructure must be taken into account in the case of oxide ceramic and sintered metals. Frequently, the bearing ratio is measured at different levels of the surface roughness and specified in %. Visual inspection is performed by means of a comparison between a polished surface and unpolished surface.




Aluminum, lapped with SiC 500, 2 min., 5 N/cm² magnification 1600x

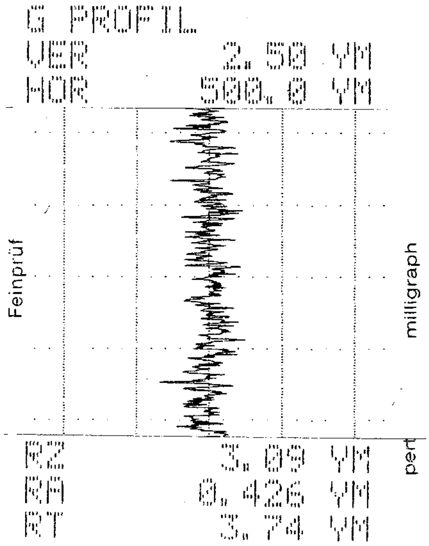
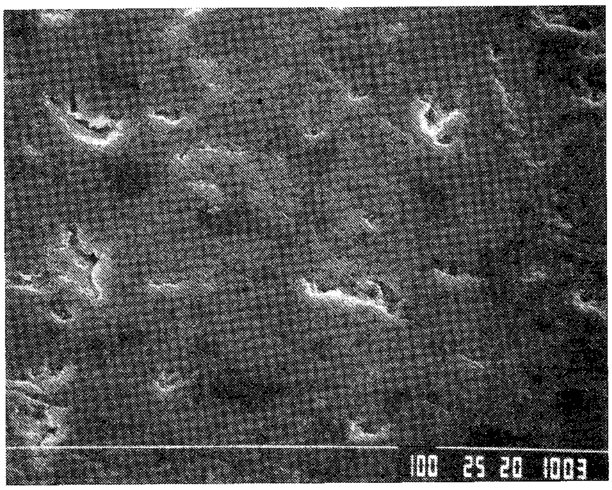



Figure 57: Shows a matt lapped aluminum part at magnification of 1600 and with the corresponding measurement diagram.




Aluminum, polished on polishing table 4/0 magnification 1600x

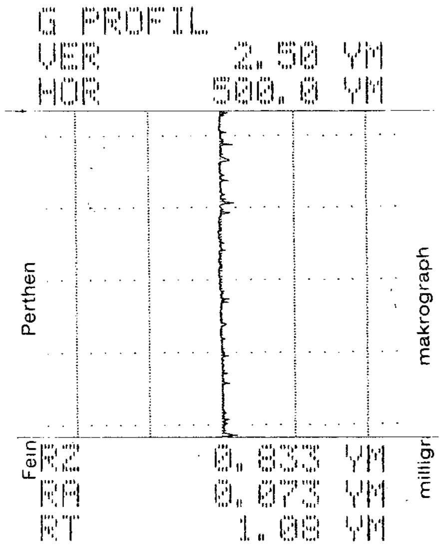



Figure 58: Same workpiece as in Figure 57, but polished on polishing table with 4/0 fine paper, material removal approx. 2-5 my, probe radius 5 my, measuring pressure 1 mN.

Accuracy

By applying the care appropriate to any everyday position machining process, lapping can be used successfully for accuracy values within fractions of 1 micrometer (micron). Taking a 100 mm diameter as an example, the following accuracies are now obtainable in practice:

| | | | |
|---|---|---|---|
| - Flatness | 0.0001 mm | 0.1 my | (0.1 micron) |
| - Parallelism | 0.005 mm | 0.5 my | (0.5 micron) |
| - Dimension | 0.001 mm | 1 my | (1 micron) |
| - Roughness Ra | 0.00001 mm | 0.01 my | (0.01 micron) |

Flatness is measured with light waves. One wavelength = 0.3 my = theoretically Lambda/2 (also see Figure 69). The other values are measured by mechanical-electronic devices. The values given above as examples can be considerably improved upon if special care is taken.
For mass production however, deviations from the above values must usually be accepted, which will be due to operating conditions. In many cases inspection is performed with equipment which cannot match the accuracy of the lapping machines. The equipment should as a rule possess a measuring range 10x the tolerance range demanded.
In lapping, however, the accuracy attainable within acceptable costs is usually so good that even the most demanding workpieces are easily within tolerance.
Designers of components (workpieces) requiring fine machining should learn more about the possibilities now offered by lapping technology.

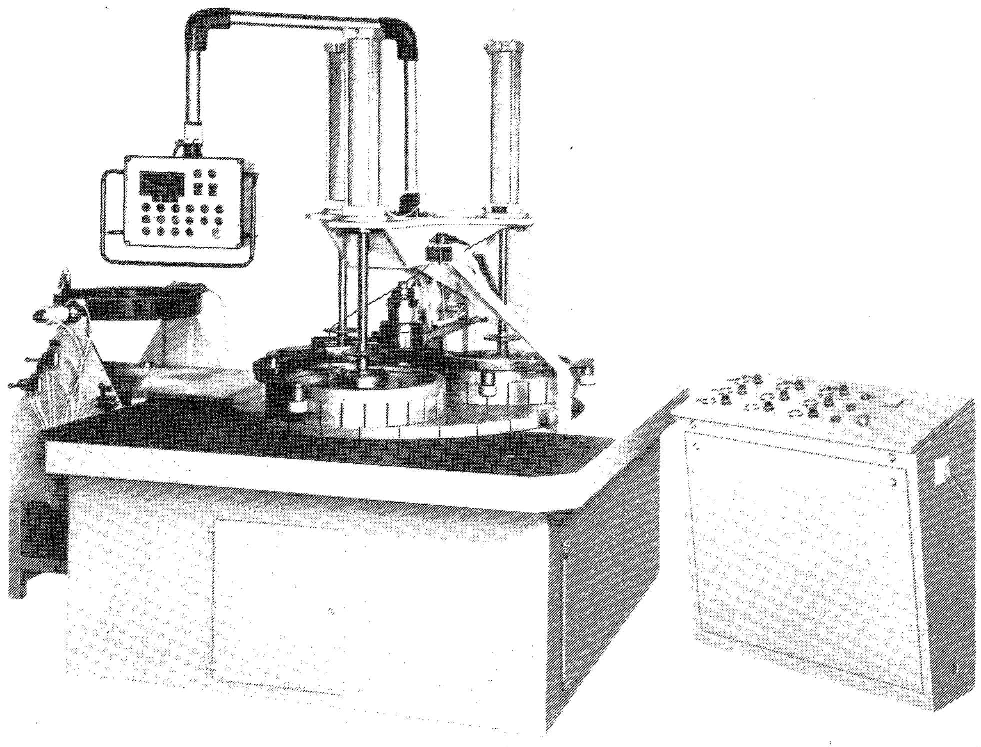


Figure 59: FLM 1250, production machine for series use and machining large parts with loading/turning system

## Aspects of Production Lapping

As today's flat lapping machines are capable of high material removal rates and therefore short machining times, the idle times are becoming more and more significant in the cost-effectiveness of the process. This trend has led to the development of loading, turning and unloading devices, which are usually designed as an integral part of the flat lapping machines, fixed to the bed and capable of adjustment to the required height.
As high material removal rates depend mainly on high loading, pneumatic cylinders (Figure 59) are often used to apply the lapping pressure on production machines. However the pressure must be appropriate to the surface, the thickness and type of workpieces, and a certain amount of experience is needed in applying it. A high-performance cooling system should be provided to dissipate the heat generated by the high material removal rates (also see Figure 74, on the left side of the machine).
Assuming allowances between 0.05 and 0.1 mm and 50% of the surface area to be lapped, lapping times usually lie in a range of 10 to 20 minutes per side. It is unfortunate that lapping is still seen only as a means of obtaining the final levels of accuracy, flatness and finish. Preground parts are usually supplied to the lapping machine with allowances between 0.02 and 0.05 mm, but it is not yet widely realized that in the same time, production machines such as that shown in Figure 59 can remove from 0.2 to 1 mm of material, depending on the surface area and material composition.

A. W. Stähli, lapping machine manufacturers, achieve economically lapping rates on 80% of all parts sub-contracted for machining, without pregrinding. The material and the surface area to be machined are more influential on the lapping process than on grinding, because lapping particles cannot be relied upon to machine an indefinitely large surface without breaking. It is thus understandable that a steel ring, e.g. diameter 200/180x20 mm, can be lapped in a shorter time than a disc of the same diameter.
Idle times assume most importance when large numbers of small parts have to be lapped on both sides. Manual turning of 1000 and more workpieces per load can take from 20 to 30 minutes, whereas the same work can be done with a special device in 2 to 3 minutes. Depending on the size of the machine and the type of loading-turning-unloading device, automatic handling is feasible for parts down to 0.2 mm thickness.

## Idle times

To minimize idle times and manual handling of the workpieces, machines are being automated more and more (Figures 41 + 42). Lapped parts must be thoroughly washed after machining. This can be performed with ultrasound in a quick-drying, non-staining fluid. The environment, i.e. the working process, washing process and handling are increasingly determining the peripheral equipment of the machine.
Existing environmental regulations require the modification of entire processes. "Clean lapping" is becoming a topical subject (also see the top of Page 17). Disposal of used lapping agent is becoming more difficult and expensive. Machining processes involving bound grit and machines with flood-type rinsing systems already conform with the new tendencies. Only washing systems using water as a cleaning agent will be permissible in future. The requirement for spotless drying will make the washing process longer and more complicated. Blind holes, threads and assembled parts will cause difficulties. Hot-air or vacuum drying is recommended for this purpose.

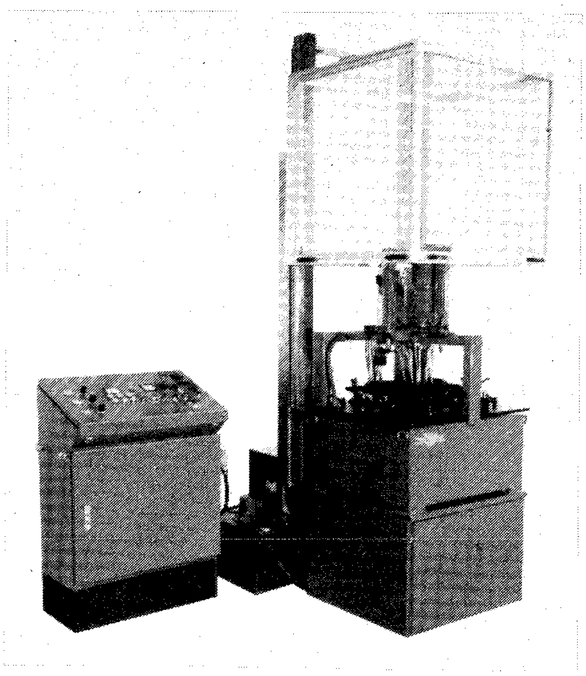


Figure 60: FLM 500-S
with protective fluid

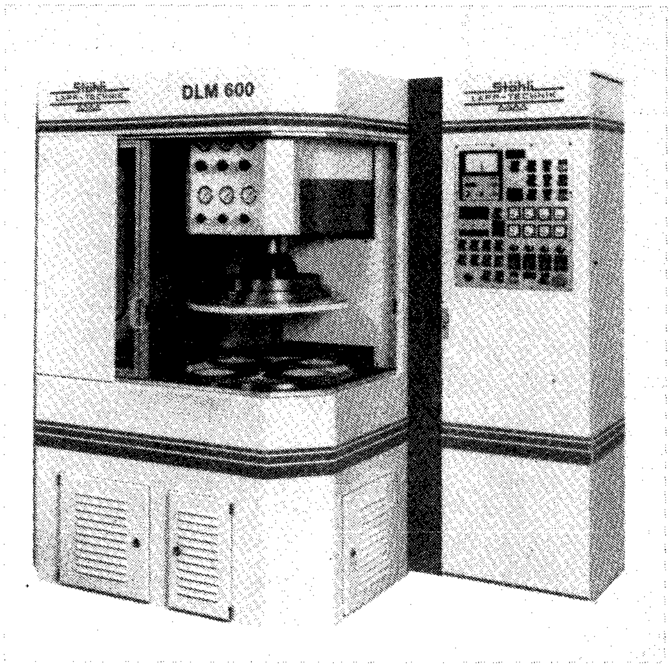



Figure 61: DLM 600-I
Two-plate lapping machine

The machines shown in Figures 60 + 61 permit dust and vapor-free working with continuous or subsequent flood-type rinsing with filtered working fluid. The abraded material is thus collected outside the machine and can be automatically filtered, dried and disposed of in this way.

## The polishing table

Surfaces lapped with loose grains are matt gray in color (Figures 8 + 9). This layer can be easily removed with a few passes on the polishing table (Figure 62). This process is used for achieving a clean and reflective lapped surface on lapped workpieces. A flat-lapped plate is used as a polishing table. It is covered with fine polishing paper and tensioned via an eccentric. There is virtually no detectable loss of flatness after this polishing process. The paper surface should be washed regularly in order to remove the abraded material. Polishing paper is supplied in 10-m lengths.

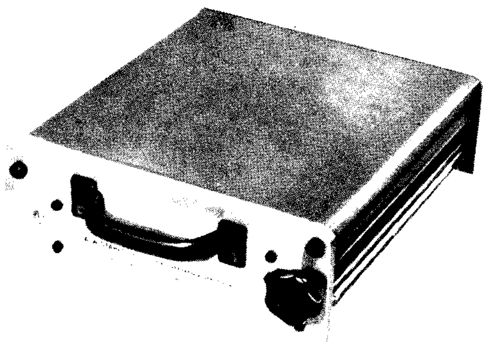


Figure 62:
Polishing table with polishing paper tensioned with eccentric.
Polishing area 300x300 mm Type I
Polishing area 400x400 mm Type II
Polishing area 500x500 mm Type III

## Unit price calculation

Lapping machines are graded according to the lapping plate diameter; although this by no means constitutes a full specification, it gives a good indication of the size of the machine. Performance data have to be taken into account. The main factor influencing the price per part is the internal diameter of the conditioning rings, because this encloses the actual area useful for lapping, and allows an estimate of the number of parts acceptable by the machine per cycle. The capacity table (Figure 63) provides reliable data on this. Taking the type FLM 1000 as an example, the conditioning rings are each 400 mm in diameter. The machine can thus accommodate approximately 5800 parts with a diameter of 5 mm, 340 parts with a diameter of 20 mm or 32 parts with a diameter of 60 mm in each conditioning ring. Each load consists of 3 conditioning rings, i.e. approximately 17400 or 1020 or 96 parts. Even assuming the relatively slow cycle time of 20 minutes, for example, a very short machining time per part nevertheless results. If the parts are not rinsed and measured while the machine is already running in the next cycle, the times for these final operations must be added to the lapping cycle time. Production lapping machines often achieve unit prices less than those for grinding.
A further advantage are the low tooling costs. If required at all, only simple plastic workholders for positioning the workpieces have to be produced.

**Capacity table**
**for round workpieces/per conditioning ring**

**Numbers assumed without workholder plates, slight variations possible Factor 0.4-0.6 to be assumed when holders used, according to the shape of the part.**

| Machine type | FLM 400 | FLM 500 | FLM 750 | FLM 1000 | FLM 1250 | FLM 1500 |
|---|---|---|---|---|---|---|
| Conditioning ring ø mm | 145 | 190 | 300 | 400 | 500 | 600 |
| Workpiece ø 5 | 536 | 1350 | 3400 | 5800 | 7500 | 10800 |
| 7,5 | 256 | 600 | 1400 | 2500 | 3330 | 4800 |
| 10 | 140 | 320 | 800 | 1400 | 1875 | 2700 |
| 12,5 | 87 | 195 | 500 | 880 | 1200 | 1725 |
| 15 | 64 | 130 | 340 | 605 | 840 | 1200 |
| 17,5 | 54 | 90 | 250 | 440 | 610 | 880 |
| 20 | 30 | 70 | 190 | 340 | 465 | 675 |
| 25 | 21 | 44 | 115 | 207 | 300 | 430 |
| 30 | 16 | 29 | 78 | 140 | 208 | 300 |
| 35 | 9 | 20 | 56 | 100 | 153 | 220 |
| 40 | 8 | 16 | 42 | 75 | 117 | 165 |
| 45 | 7 | 12 | 32 | 58 | 92 | 132 |
| 50 | 5 | 9 | 26 | 47 | 75 | 108 |
| 55 | 4 | 8 | 21 | 40 | 61 | 89 |
| 60 | 3 | 7 | 19 | 32 | 52 | 75 |
| 65 | 3 | 5 | 15 | 27 | 44 | 63 |
| 70 | 2 | 4 | 13 | 23 | 38 | 55 |
| 75 | 1 | 4 | 11 | 21 | 33 | 48 |
| 80 | 1 | 3 | 9 | 19 | 29 | 42 |

| Machine type | FLM 400 | FLM 500 | FLM 750 | FLM 1000 | FLM 1250 | FLM 1500 |
|---|---|---|---|---|---|---|
| Conditioning ring ø mm | 145 | 190 | 300 | 400 | 500 | 600 |
| Workpiece ø 85 | 1 | 3 | 8 | 16 | 25 | 37 |
| 90 | 1 | 2 | 8 | 14 | 23 | 33 |
| 95 | 1 | 2 | 7 | 13 | 20 | 29 |
| 100 | 1 | 1 | 5 | 11 | 18 | 27 |
| 110 | 1 | 1 | 5 | 9 | 15 | 22 |
| 120 | 1 | 1 | 4 | 8 | 13 | 18 |
| 130 | 1 | 1 | 3 | 7 | 11 | 15 |
| 140 | 1 | 1 | 2 | 5 | 9 | 13 |
| 150 | | 1 | 2 | 4 | 8 | 12 |
| 160 | | 1 | 1 | 4 | 7 | 10 |
| 170 | | 1 | 1 | 3 | 6 | 9 |
| 180 | | 1 | 1 | 3 | 5 | 8 |
| 190 | | 1 | 1 | 2 | 5 | 7 |
| 200 | | | 1 | 2 | 4 | 6 |
| 250 | | | 1 | 1 | 2 | 3 |
| 300 | | | 1 | 1 | 1 | 2 |
| 350 | | | | 1 | 1 | 1 |
| 400 | | | | 1 | 1 | 1 |
| 500 | | | | | 1 | 1 |
| 550 | | | | | | 1 |

Figure 63: Capacity table for round workpieces/per conditioning ring. The outer diameter must be calculated if the parts are irregularly shaped. The numbers are calculated without workholder plates, slight variations are possible. A factor of 0.4-0.6 must be assumed when workholders are used.

## Measuring

The measurement of thickness and parallelism is relatively easy using mechanical or electronic measuring instruments. Electronic measuring instruments with high sensitivity and several measuring ranges down to 0.0001 mm, combined with differential probes, have proven their usefulness in practical applications. They ensure superior precision combined with fast and reliable work.

By contrast, surface finish quality is more difficult to measure. The three most common methods for specifying a surface roughness value are shown in Figures 46, 47 and 48.

The probes are usually provided with tips of 2 and 5 my radius, and are applied to the work with very low pressures (e.g. 0.5 to 1 mN). The surface profile is shown by means of a writing unit or displayed on a screen. Figures 51, 52, 53, 57 and 58 show such recordings.

Flatness measurements are even more complex to obtain than the surface finish quality. However, the interference test instruments now in use (Figure 65 and 66) are precise and simple tools. However, these instruments are suitable only for reflective surfaces.

Newer laser measuring instruments with or without oblique-light measurement (Figure 67) can measure both polished lapped surfaces and matt surfaces. With oblique-light measurement, matte surfaces up to approx. Rt 5 my can be measured. Here, the wavelength λ Lambda of 4-6 my is significantly larger than with the vertical method (λ 0.6 my). An interference line λ/2 shows 2-3 my errors. Light from coarse ground surfaces is diffused due to the larger roughness and is unsuitable for testing.

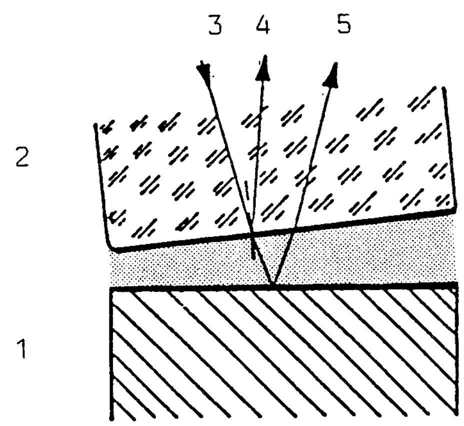



Figure 64:
Principle of testing with interference unit. Schematic for monochromatic light.

1 = Testpiece
2 = Optical ?
3 = Incident ray
4 = Coherent rays
5 = Coherent rays

Figure 64 shows the functional principle of these instruments with monochromatic light. Owing to the various paths taken by the light rays, the eye perceives an interference pattern of light and dark stripes. The pattern of the tested surface can be deduced depending on the shape of these interference lines. This representation can be compared to contour lines on maps (also see Figures 68 + 69).

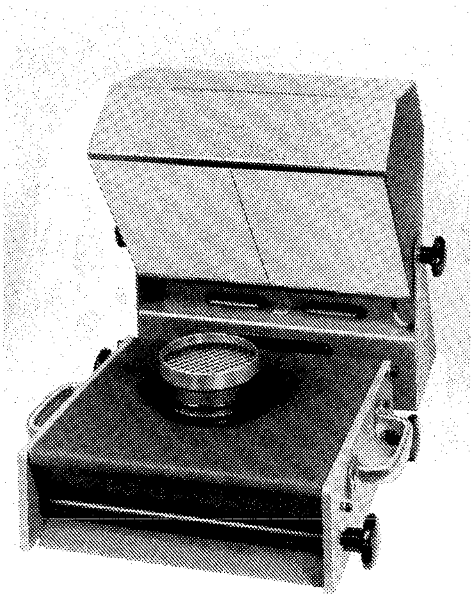


Figure 65: Interference tester
Flat measuring plate for testing the planeness of lapped surfaces (direct measurement).

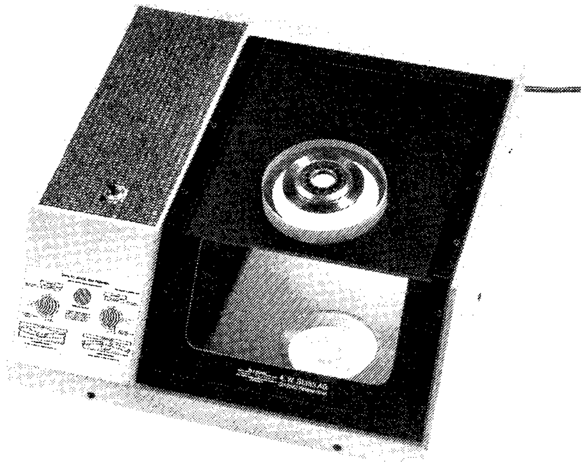
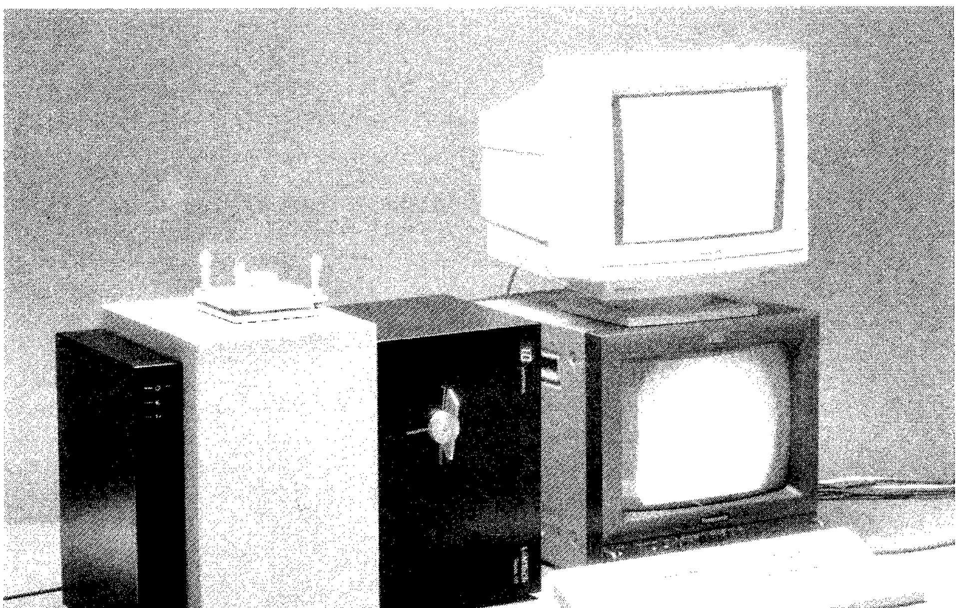


Figure 66: New instrument for distortion-free flatness measurement. The workpiece is laid on the flat measuring plate and examined in the mirror (indirect measurement).

Laser flatness measuring instrument

Interferometric measuring instrument TOPOS for the twodimensional and contactless flatness testing. Due to the four calibrated sensitivity settings of 0.5, 1, 2 and 4 µm per interference fringe, this instrument will not only be suitable for the measuring of reflective surfaces, but in particular for fine-finished surfaces such as lapped surfaces, even with coarser grain, or for finish-ground surfaces.
The instrument can be extended to a complete computer-aided measuring system for a twodimensional determination of the surface shape supplying a quantitative output and a varied graphic representation of the relevant results (picture). The graphics can be output on different printers. The absolute measuring accuracy is down to 0,1 µm. The measuring range is up to 100 µm. Automatic measuring procedures can be programmed and stored. Measurements can be stored for comparison with reference surfaces or for the determination of wear.



A laser flatness measuring instrument now permits contact-free flatness measurement with the accustomed quality of 0.3 microns stripe pattern. This now also permits testing of highly accurate, polished surfaces without contact. The test results shown on the video monitor can be printed out and submitted with the workpiece as a proof of quality. This clear advantage is now a necessity for QA (quality assurance).

In combination with computer evaluation, this clears the way for automation of the entire lapping and polishing process. In this case, handling systems transport the workpiece under the optical system, or from the optical system into the prepared packages.

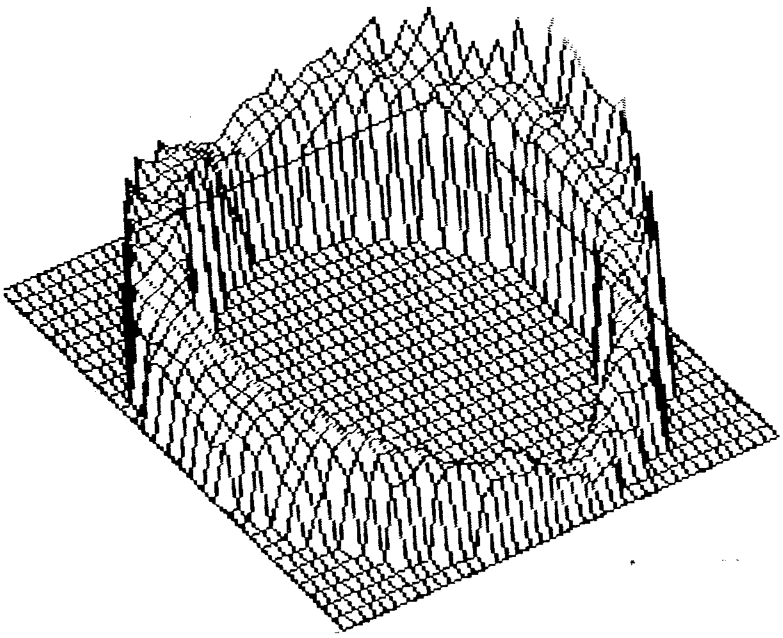


Figure 68:
Evaluation of a phase pattern and three-dimensional representation of the measured surface. Planarity error less than 2 my.

Checking the working plate

The working plate on the machine must naturally also be checked for flatness, as this is one of the most important factors influencing the accuracy and cost-effectiveness of the lapping process.

Checking should be carried out once or two times per day, and the conditioning ring adjustment is entered in a log. The first and most simple inspection method is a precise straight edge laid across the working plate. Sliding the straight edge from side to side indicates the location of the rotation point, or whether the working plate is convex or concave (Figure 69).

The second inspection method is a measuring beam with several dial gauges that were previously adjusted on an exact base surface (granite table) (Figures 31 + 32).

The third inspection method is a brass test block lapped on the machine. Its flatness error closely approximates the error on the working plate in most cases. It must be borne in mind here that a convex test-block surface indicates a concave working plate (Figure 69).

In practice, the straight-edge test should always be done first. Only then should an additional test be performed with the test block. Inspection errors are avoided if this sequence is observed.

The test piece should copy only that part of the lapping plate surface which it occupied within the conditioning ring, i.e. only in the center of the conditioning ring. If the working plate or test block is excessively convex a relatively long time will be required until the final pattern is obtained (wobbling of the test block on the convex working plate). The test block method has been largely superseded by the use of measuring rulers (Figure 31).

The amount of material removed from the plate should be such as to correspond to an over-correction of the workpiece flatness. If the error detected is still outside the permissible limits, the machine may be allowed to run for some time with no workpieces in the rings. If necessary, extra pressure can be applied or medium-sized workpieces can be lapped as an aid to material removal during correction.

Within the 100 to 400 mm workpiece diameter range for example, flatness to the quality of 1 interference band (0.0003 mm) can be obtained only if the lapping plate is at least as flat or slightly convex (also see Page 16 "The working plate"). Only a single-plate lapping machine working with conditioning rings can be relied upon to maintain this level of accuracy over a prolonged period. The accuracy achieved must be documented by measuring the working plate. Practical experience has shown that a certain workpiece can also lead to a certain state of the working plate. The next time identical or similar workpieces are machined, the user can benefit from the previously recorded measurement and correction values (Figure 32).

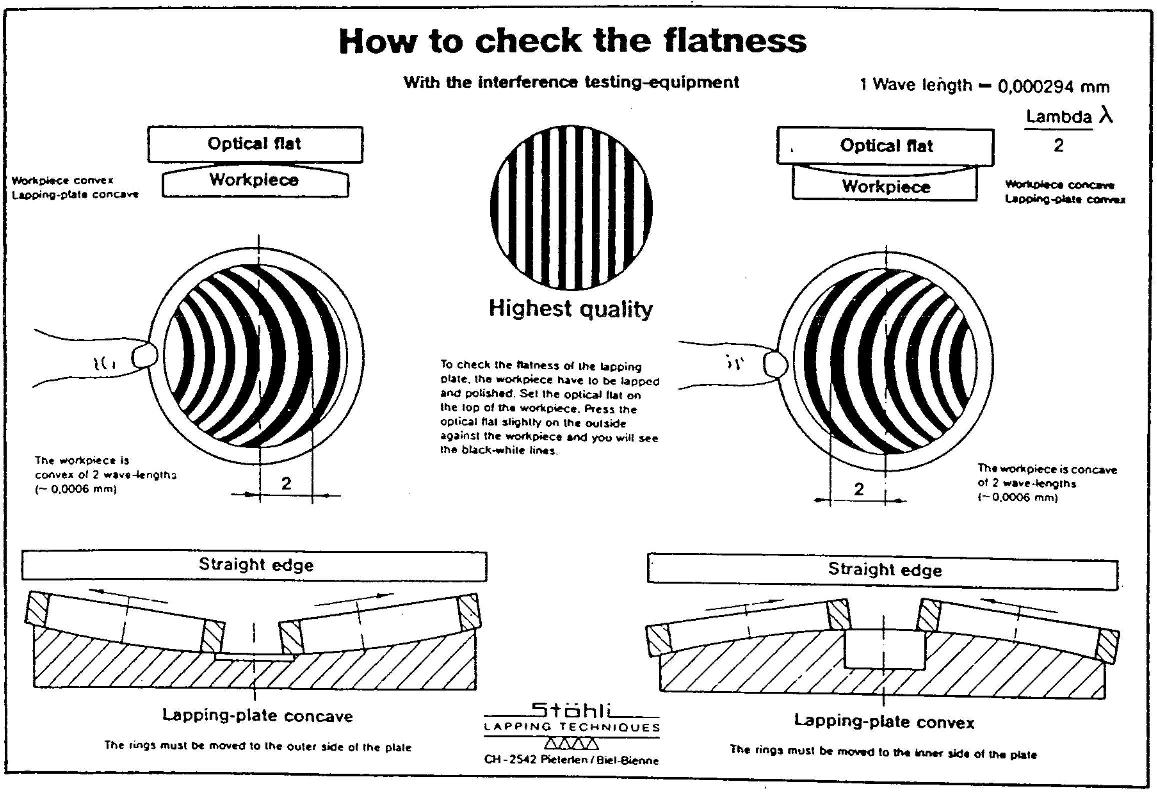



Figure 69:
Workpiece and test-block method, plus inspection of the lapping plate flatness using a straight edge.

## What Types of Workpiece are Lapped?

Practically all workpieces comprising surfaces which need to be flat and parallel are lapped. The material is of no account: Anything can be lapped, from plastics to diamond itself, and the type of material affects only the rate of material removal and the surface quality obtained. Excellent results are achievable when the correct lapping agent and suitable lapping machine are used. Many production lines today are oriented towards lapping, and the lapping machine is incorporated in transfer sections (Figures 41 + 42). Machines are now commercially available for handling workpieces weighing from a few grammes up to a ton.

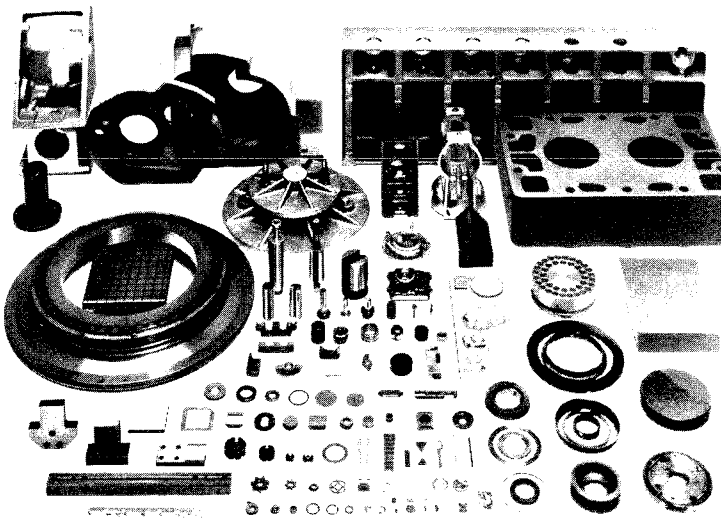


Figure 70: Examples of lapped workpieces

Figure 71: Mirror-polished steel injection mold for compact discs (CDs)

## Diamond lapping

In earlier days, hand lapping and polishing frequently resulted in chipping at the workpiece edge, at holes or recesses, especially when the lapping medium was carried by textile or hardwood surfaces. The removal of soft areas in a surface structure could produce a dimpled finish like an orange skin. For modern, high-grade material removal, and for the very hard materials now widely used, traditional lapping media (corundum, silicon carbide, boron carbide) cannot meet the requirements of particle size constancy and material removal performance. This led to the development of diamond lapping agents and the associated methods. This has made possible:

- Brilliantly polished surfaces with high flatness values and without any associated disadvantages, even for materials with very different microstructure hardness values.
- Reduced lapping and polishing times, and therefore low wage and machine costs.
- Lower lapping medium costs in many cases.
- Improved automation possibilities for lapping machines.
- New possibilities with the use of fixed-grit plates.
- Nothing to prevent "clean lapping".

It is not easy for the uninitiated to classify the many different diamond powders available on the market, or to select the right powder for the task in hand. Frequently, a randomly selected powder is used for reasons of time and costs, without previous comparisons. Manufacturers of lapping and polishing machines have a wealth of experience in this field and offer diamond agents that have proven their worth in practical use.

Some information on the manufacture of diamond powder is given below:

- Natural diamonds are one source of diamond powder. Waste products from jewelry-quality diamonds and diamonds with visual defects are broken into the desired qualities, sifted, washed or sedimented. The grain shape is monocrystalline, i.e. the grains fracture in a single plane as with granite blocks, into smaller, sharp-edged pieces.

- The first synthetic diamond produced from graphite (originally by means of the "Du-Pont explosion method") was polycrystalline. This type fractures in various planes, i.e. multi-block.

- Synthetic diamonds, both monocrystalline and polycrystalline, are nowadays produced under extremely high pressure. The grain shape and strength can be influenced to a great extent using a special technique.

Whether monocrystalline or polycrystalline diamond is used when lapping or polishing depends on the workpiece material, the carrier (working plate), the carrier medium and the working process. Of crucial importance is good calibration, adequate wetting (no lumps or agglomerates), long-term suspension in the medium (floating) as well as the lubricant-film behavior on the carrier or in the working gap. The quantity, type of carrier, removal of abraded material (chip flow) etc. must be intermatched. Successful lapping with diamond also depends to a great extent on operation of the machines. The best diamond agents and the most refined technical equipment are useless if the knowledge, experience and attitude of the operating personnel do not meet the high demands placed on them. Successful use of the lapping technique is ensured if these technical and human requirements are fulfilled.

Diamond mediums are applied by specially developed spray devices (Figure 75) which ensure that the fluid remain uniformly mixed and precisely metered, time-adjustable quantities are supplied to the working plate. If various grit sizes must be used, only the container, hoses and nozzles have to be replaced.

In theory, these micro-grit diamond media can be used on any type of lapping machine. However, there are great differences with respect to good material-removal performance and the corresponding polishing method. Only robust and massively constructed lapping and polishing machines are suitable here. Working plates used for job lapping consist of steel, cast iron or copper in most cases and use special profile shapes. Good results can be achieved by using spiral-shaped multi-metal plates. Steel, copper, aluminum, tin, wood and fabric plates are used for polishing.

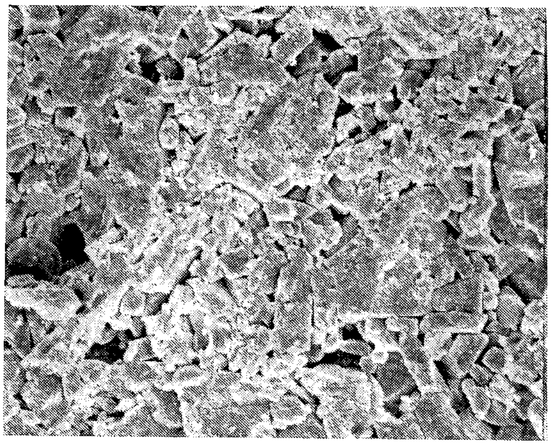


Figure 72: Aluminum oxide ceramic $Al_2 O_3$, pre-lapped with silicon carbide, 400 grit, 17 my. The intact, cleanly broken-out microstructure is clearly visible.

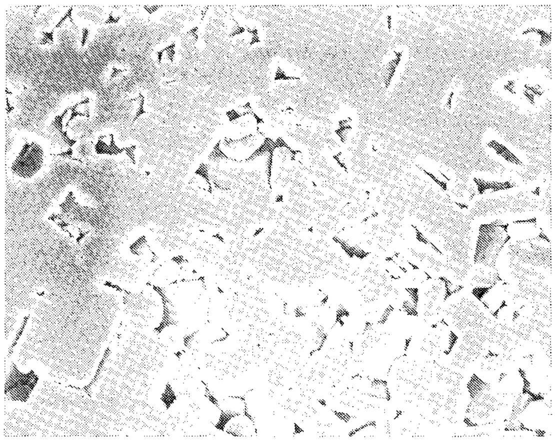


Figure 73: The same workpiece as in Figure 72, but machined with diamond.
D 2-3 my on steel plate.
The sharp-edged cutting result is clearly visible.
Ra = 0.12 my, Tp 80%

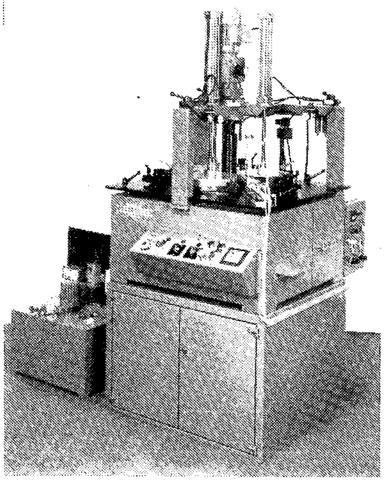


Figure 74: FLM 500-DL, diamond lapping machine with annular drive, water cooling system, drive power 3.5 kW.

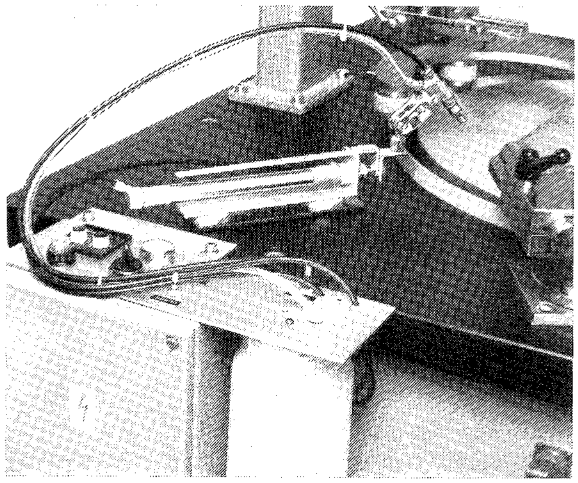


Figure 75: Diamond spray unit

In polishing, the amount of diamond medium consumed is relatively low. Depending on the volume of material removed, the figure is only 6-8 Carats/day for a lapping machine with a plate diameter of 400 mm. The machining time compared with the use of silicon carbide can be shorter by a factor of 10. Today, diamond powder is very widely used, allowing much shorter lapping and polishing times, greatly increased accuracy, better surface finish and reduced costs by comparison with the use of other media. The microstructural properties of the workpiece material can also favor choosing diamond powder. Diamond is now used to machine extremely hard materials such as hardened steel, special alloys, glass, silicon, carbide metal, ceramics, sapphire or even diamond itself. Diamond is used for micro-fine lapping or polishing of softer materials, e.g. steel of all types, nonferrous metals, graphite, ferrite, and even plastics.

Examples of such workpieces include: Sliding rings, sealing rings, plungers, ferrite cores, contacts, molybdenum parts, titanium parts, surface plates, gauge blocks, optical flats, sapphire glass, reversible carbide tips, carbide metal cutters, hard ceramics, silicon nitride and tungsten nitride rings, diamond tools.

In this connection, the special additions below may be of interest to the reader:

"Diamond for lapping and polishing highly accurate components" / JDR 20 (1986), No. 4
"Lapping with diamond on 2-plate lapping machines" / JDR 24 (1990), No. 1.

The foregoing articles should give an idea of the very promising future which can be expected of the lapping and polishing process. The industry is increasing acknowledging lapping as a cost-effective, precision machining method. University studies and seminars are contributing a fuller understanding of its possibilities. A. W. Stähli AG regularly offers its own practical seminars. These seminars are also oriented towards beginning users or operating personnel of users. As a complement to this article, films in three languages for schools and production management are available from the author.

A further publication has been produced on the topic "Dual-plate lapping" and is available from Läpp-Technik, A. W. Stähli AG.


Figure 76: Dual-plate lapping machine DLM 900-I

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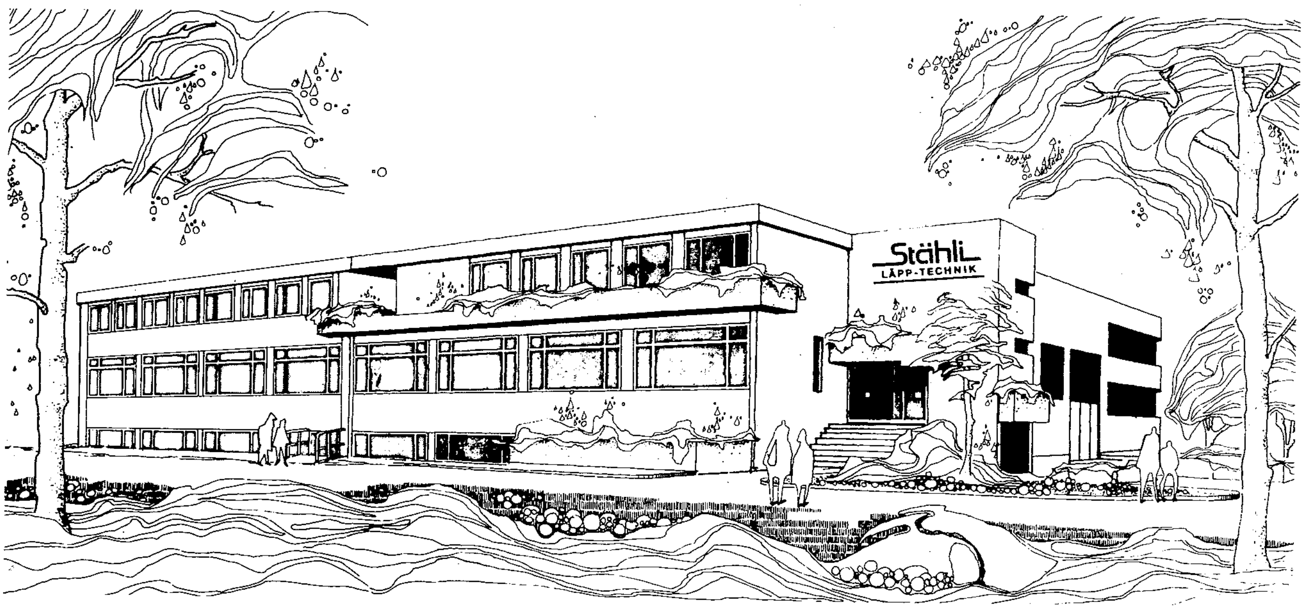
# LAPPING TECHNIQUES





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