Lecture 2: Basic Elements and Mechanisms of Machine Tools

Dr. Parviz Kahhal

مقدمه

- مشخصه ماشین های برش فلزات (ماشین ابزار) نسبت به ماشین های شکل دهی فلزات، دقت تولید باالتر می باشد.
- آن ها برای تولید تعداد نسبتا کمتری استفاده می شوند، بالعکس، ماشین های شکل دهی فلزات برای کمیت های تولید باالتر استفاده می شوند.
- ماشین های ابزار حدود ۷۰% از ماشین های عملیاتی تولیدی را در صنعت تشکیل می دهند.
- درصد های مختلف عملیات های مختلف ماشین های ابزار در اسلاید بعدی نشان داده شده اند.

مقدمه

TABLE 2.1
Percentage of Different Types of Operating Machine Tools

Type of Machine Tool	Percentage
Lathes including automatics	34
Grinding	30
Milling	15
Drilling and boring	10
Planers and shapers	4
Others	7

مقدمه

- طراحی موفق ماشین ابزار نیازمند معلومات بنیادی زیر می باشد:

1. مکانیک فرآیند های ماشینکاری برای ارزیابی مقدار و جهت و همچنین کنترل نیرو های برش.
2. قابلیت ماشینکاری مواد مختلف که قرار است ماشینکاری شوند
3. خواص مواد مورد استفاده برای ساخت قطعات مختلف یک ماشین ابزار
4. تکنیک های ساخت که برای تولید هرکدام از قطعات ماشین ابزار به صورت اقتصادی به کار گرفته می شوند.
5. ماندگاری و قابلیت مواد ابزار مختلف
6. اصول اقتصاد مهندسی

مقدمه

- قابلیت تولید یک ماشین ابزار توسط
  - o تعداد قطعه تولید شده در واحد زمانی،
  - o یا نرخ براده برداری حجمی،
  - o یا نرخ براده برداری مخصوص به ازای توان واحد مصرف شده،
- اندازه گیری می شود.
- سطح قابلیت تولید (بهره وری) را می توان با استفاده از روش های زیر ارتقا بخشید:

1. افزایش سرعت ها و نرخ تغذیه ماشین
2. افزایش توان در دسترس ماشین ابزار
3. استفاده از چند ابزار و یا ماشینکاری چند قطعه کار به صورت همزمان
4. افزایش سرعت حرکت واحد های اجرایی در زمان های غیر ماشینکاری
5. افزایش سطح اتواسیون برای واحد های اجرایی ماشین های ابزار و اجزا قابل تعویض
6. به کارگیری تکنیک های کنترل مدرن نظیر NC و CNC
7. انتخاب مناسب فرآیند های ماشینکاری بر اساس ماده، پیچیدگی شکل، دقت و صافی سطح قطعه ماشینکاری شده.
8. به کارگیری قید ها و بند ها که قطعه کار را در کمترین زمان ممکن مکان یابی و محکم می کند.

مقدمه

- ماشین های ابزار به گونه ای طراحی شده اند که ماکزیمم بهره وری ممکن را به دست آورند و دقت و صافی سطح پیش بینی شده رادر عمر سرویس دهی خود مهیا نمایند.
- برای ارضا این نیاز ها، هر جزء ماشین ابزار باید به صورت جداگانه و تا حد امکان صلب طراحی شود و سپس از نظر رزونانس و استحکام بررسی شود.
- به علاوه، ماشین ابزار باید یک پایداری مناسب داشته و دارای ویژگی های کلی زیر باشد:

1. سفتی استاتیکی بالا برای همه اجزا ماشین ابزار مانند ساختار، مفاصل، و اسپیندل ها.
2. جلوگیری از فرکانس های طبیعی غیر قابل قبول که باعث رزونانس در ماشین ابزار می شوند.
3. سطح ارتعاش قابل قبول
4. ظرفیت میرایی مناسب
5. سرعت و نرخ تغذیه بالا
6. نرخ های سایش پایین در قطعات لغزشی
7. اعوجاج حرارتی پایین برای اجزا مختلف ماشین ابزار
8. هزینه پایین طراحی، توسعه، تعمیر، نگهداری و ساخت.

مقدمه

- ماشین های ابزار بر طبق ویژگی هایشان به انواع زیر دسته بندی می شوند:

1. ماشین های با اهداف عمومی (انیورسال)، که برای ماشینکاری طیف وسیعی از محصولات به کار می روند.
2. ماشین های با اهداف خاص، که برای ماشینکاری محصولات با شکل یکسان واندازه متفاوت به کار می روند.
3. ماشین های با اهداف محدود، که یک طیف باریک از عملیات ها را روی محصولات گوناگون انجام می دهند.

مقدمه

- ماشین های ابزار بر اساس سطح دقت به انواع زیر دسته بندی می شوند:

1. ماشین های ابزار با دقت معمولی، که شامل اکثر ماشین های با اهداف عمومی می باشد.
2. ماشین های ابزار با دقت بالاتر، قابلیت تولید تولرانس های پایینتر را دارند.
3. ماشین های ابزار با دقت بسیار بالا، که قابلیت تولید قطعات بسیار دقیق را دارند.

مقدمه

- عملکردهای اصلی یک ماشین ابزار نگه داری قطعه کار، نگه داری ابزار و دستیابی به حرکات نسبی مورد نیاز برای تولید هندسه مطلوب قطعه می باشد.
- ماشین های ابزار شامل اجزا زیر می باشند:

1. یک ساختار متشکل از بستر (میز)، ستون، یا قاب
2. لغزنده ها و ضمائم ابزار
3. اسپیندل ها و یاتاقان های اسپیندل ها
4. یک سیستم راننده (واحد توان یا تغذیه)
5. اجزا نگه دارنده ابزار و قطعه کار
6. سیستم های کنترل
7. یک اهرم بندی انتقال

مقدمه

- تنش های تولید شده در حین ماشینکاری، که تمایل به تغییر شکل ماشین ابزار و یا قطعه کار دارند، معمولا توسط یکی از فاکتور های زیر به وجود می آیند:

1. بار های استاتیکی شامل وزن ماشین و قطعات مختلف
2. بارهای دینامیکی که توسط قطعات دورانی یا رفت و برگشتی به وجود می آیند.
3. نیروهای برشی تولید شده توسط فرآیند براده برداری

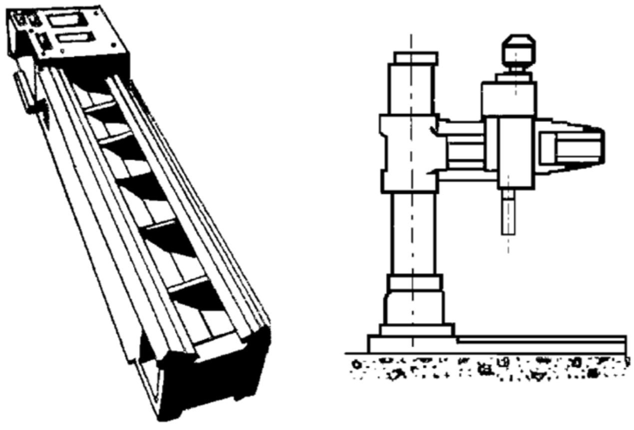
- بار های استاتیکی و دینامیکی روی کارآیی ماشین در مرحله پرداخت تاثیر می گذارند.
- درجه نهایی دقت نیز تحت تاثیر تغییر مکان ناشی از نیروهای برشی قرار می گیرد.

ساختار ماشین های ابزار

- ساختار ماشین ابزار شامل یک بدنه، که بقیه قطعات ماشین را تحمل و در خود جا می دهد، می باشد.
- شکل اسلاید بعد یک بستر ماشین ابزار رایج مربوط به ماشین تراش و یک قاب ماشین دریل را نشان می دهد.
- عملکرد های اصلی ساختار ماشین شامل موارد زیر می باشند:

1. قابلیت ساختار یا بستر برای مقومت در برابر اعوجاج ناشی از بار های استاتیکی و دینامیکی
2. پایداری و دقت قطعات متحرک
3. مقاومت به سایش شیار هدایت کننده (راهنما)
4. عاری از تنش های پسماند
5. میرا کننده ارتعاش

ساختار ماشین های ابزار



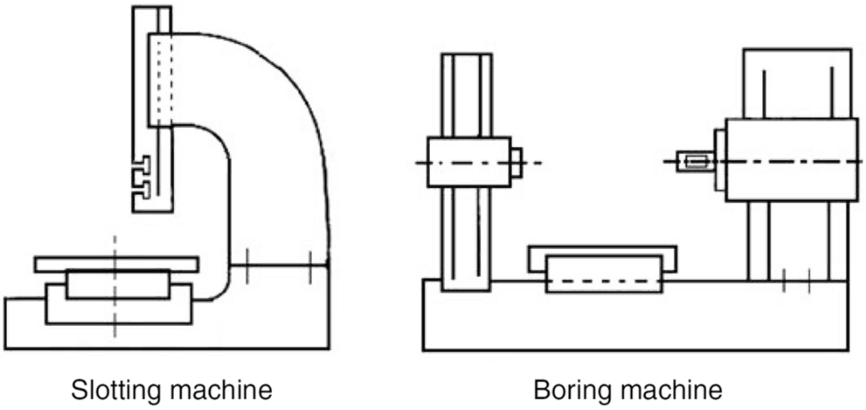
Lathe bed   Frame of radial drill

FIGURE 2.1 Typical bed of center lathe and frame of a drilling machine.

ساختار ماشین های ابزار

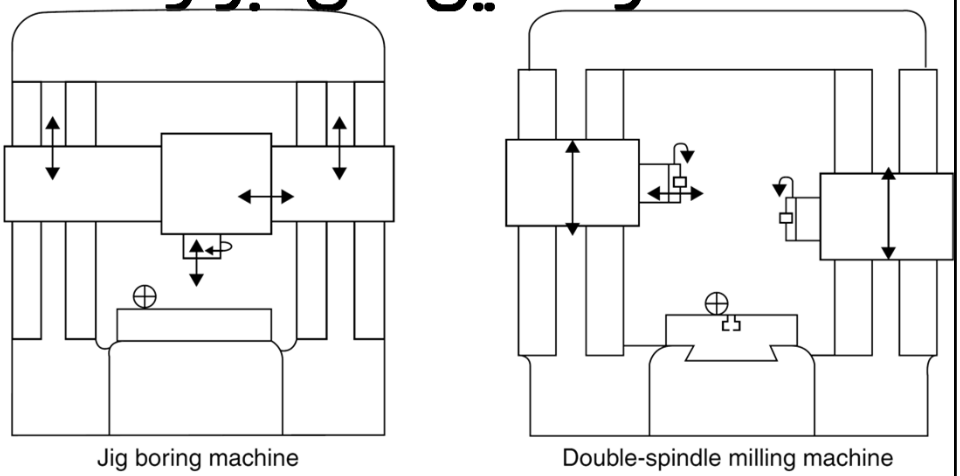
- ساختار ماشین های ابزار به دو دسته قاب های باز و بسته تقسیم می شوند.
- قاب های باز قابلیت دسترسی عالی به ابزار و قطعه کار را فراهم می کند. نمونه های رایج قاب های باز را می توان در ماشین های تراش، فرز، سنگ زنی، شیار زنی و داخل تراشی مشاهده نمود.
- قاب های بسته را می توان در ماشین های صفحه تراش و فرز های با دو اسپیندل مشاهده نمود.
- ساختار یک ماشین ابزار ابزار و قطعه کار را گرفته و راهنمایی می کاند و موقعیت نسبی آن ها را در حین فرآیند ماشینکاری فراهم می کند.
- ساختار های ماشین ابزار باید به گنوای طراحی شوند که بدون تغییر مکان، نیرو های برش و وزن قطعات متحرک را به شاسی منتقل نمایند.

ساختار ماشین های ابزار



Examples of open frames (C-frames).

ساختار ماشین های ابزار



Examples of closed frames.

ساختار ماشین های ابزار

- پیکر بندی ساختار ماشین ابزار توسط چیدمان حرکات ضروری برش و تغذیه و طول کورس آن ها و اندازه و ظرفیت ماشین مقرر می شود.
- در همین راستا، انهدام براده، حمل و نقل، نصب و نگهداری نیز در نظر گرفته می شوند.
- نرخ برداشت ماده تعیین کننده ظرفیت توان ماشین ابزار و در نتیجه مقدار نیروهای برشی خواهد بود.
- درجه دقت تولید تحت تاثیر تغییر شکل و خیز ساختار است، که باید در حدود تعریف شده نگاه داشته شوند.
- ارزشیابی رفتار ماشین ابزار توسط ارزیابی خصوصیات استاتیکی و دینامیکی آن انجام میگیرد.

ساختار ماشین های ابزار

- **خصوصیات استاتیکی**
- این خصوصیات در رابطه با خیز (تغییر مکان) ثابت تحت عوامل زیر می باشند.

1. بارهای عملیاتی برشی ثابت
2. وزن اجزا متحرک
3. اصطکاک
4. نیروهای اینرسی

- این عوامل یر روی دقت قطعات ماشینکاری شده موثرند و معمولا توسط سفتی استاتیکی اندازه گیری می شوند.
- **خصوصیات دینامیکی**
- این خصوصیات اغلب توسط خیز دینامیکی و فرکانس های طبیعی تعیین می شوند.
- این خصوصیات بر پدیده چتر ماشین ابزار و در نتیجه پایداری عملیات ماشینکاری موثرند.

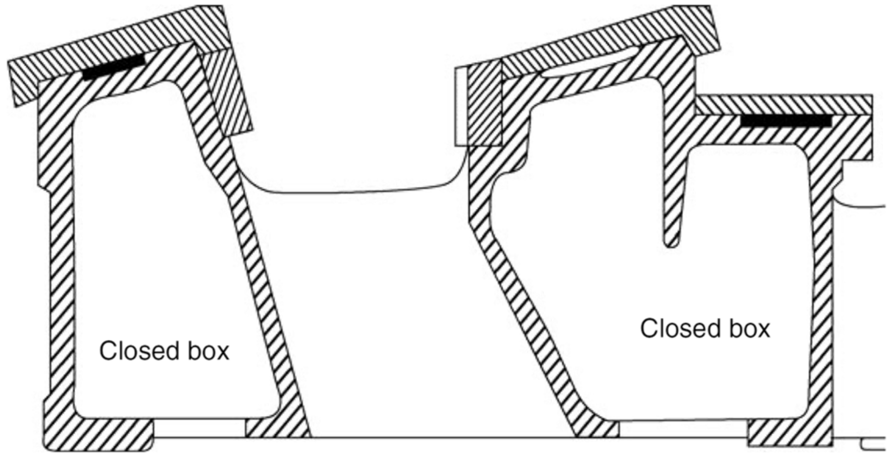
ساختار ماشین های ابزار

- خیز استاتیکی و دینامیکی یک ماشین ابزار به موارد زیر بستگی دارد:

1. کدامیک از نیروهای عملیاتی منتقل و توزیع می شوند
2. رفتار هر واحد ساختاری تحت شرایط عملیاتی

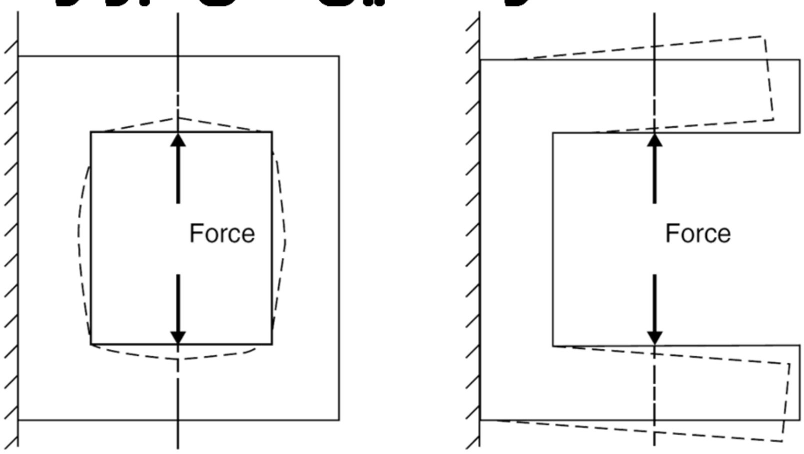
- جز تیر مانند، با سطح مقطع مستطیل توخالی، برجسته ترین جز می باشد.
- ساختار های با قاب بسته، با اینکه تحت تاثیر بار، تغییر شکل می دهند، امتداد محور های مرکزی ان ها بدون تغییر باقی می ماند.
- بر همین اساس ، در یک جابجایی محوری (نه جانبی) ابزار نسبت به قطعه کار دقت تغییر نمی کند.
- قاب های باز را می توان با یک جز دیگر ساپورت نمود.

ساختار ماشین های ابزار



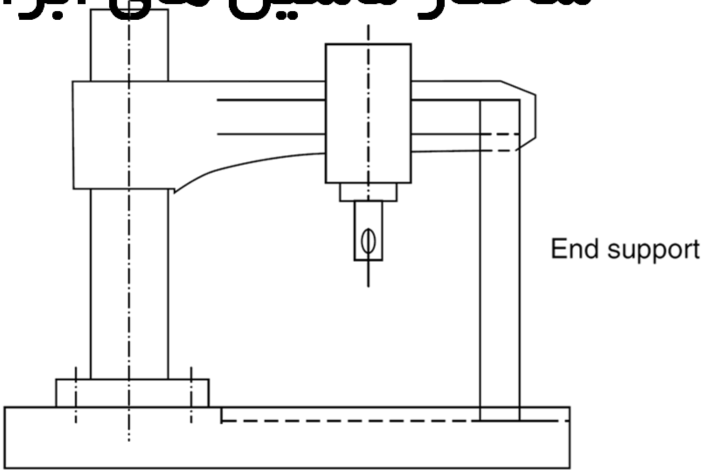
Hollow box sections of the lathe bed.

ساختار ماشین های ابزار



Deformation in open and closed frames.

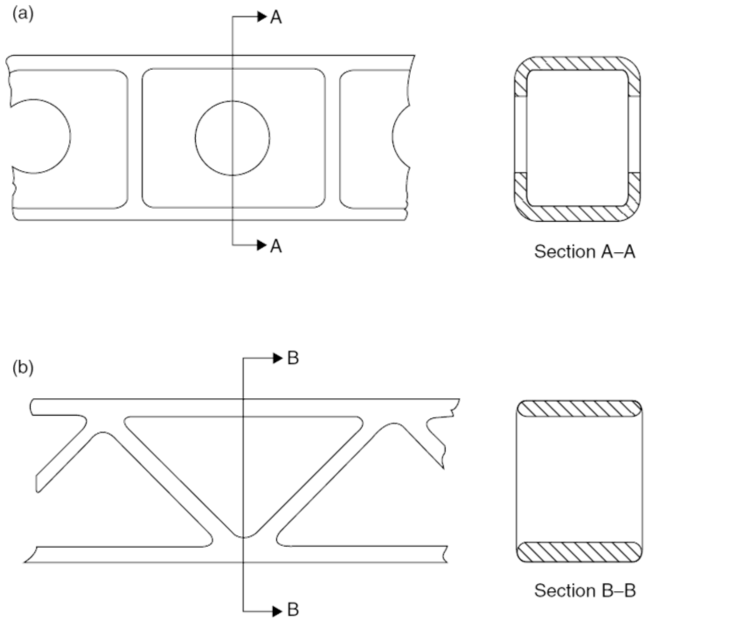
ساختار ماشین های ابزار



Radial drilling machine with end support.

ساختار ماشین های ابزار

- سفتی و میرایی ساختار ماشیت ابزار به تعداد و نوع مفاصل مورد استفاده برای اتصال اجزا مختلف ساختار بستگی دارد.
- هر چه تعداد مفاصل کمتر باشد، سفتی ساختار بیشتر و قابلیت میرایی آن کمتر می باشد.
- سیستم دنده ای (Ribbing System) یک روش موثر برای افرایش سفتی ساختار ماشین ابزار می باشد.
- در شکل اسلاید بعد، پشت بند های عمودی، سفتی را در برابر خمش عمودی افزایش می دهند ولی در خمش افقی تاثیری ندارند.
- چیدمان پشت بند های قطری، سفتی ساختار را در برابر خمش و پیچش افزایش می دهد.
- در برخی موارد، برای از بین بردن حرکت نوسانی که معمولا روی دسته انتهایی عمل می کند، از راهنما های عقبی بلند تر استفاده می شود (اسلاید ۲۸)
- قاب های ماشین های ابزار می توانند ریخته گری شده یا جوشکاری شوند. ساختار های جوشکاری شده از لحاظ هزینه به صرفه تر می باشند.



Arrangement of stiffeners in machine tool beds: (a) vertical and (b) diagonal stiffeners.

ساختار ماشین های ابزار

Raised guideways

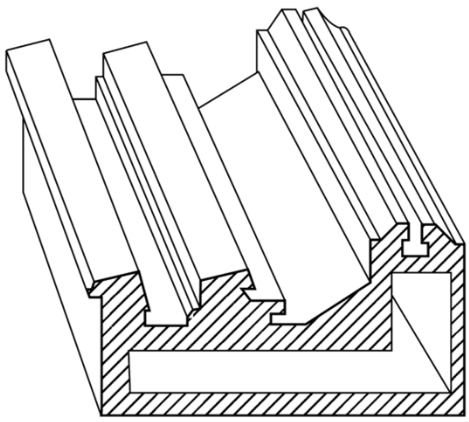
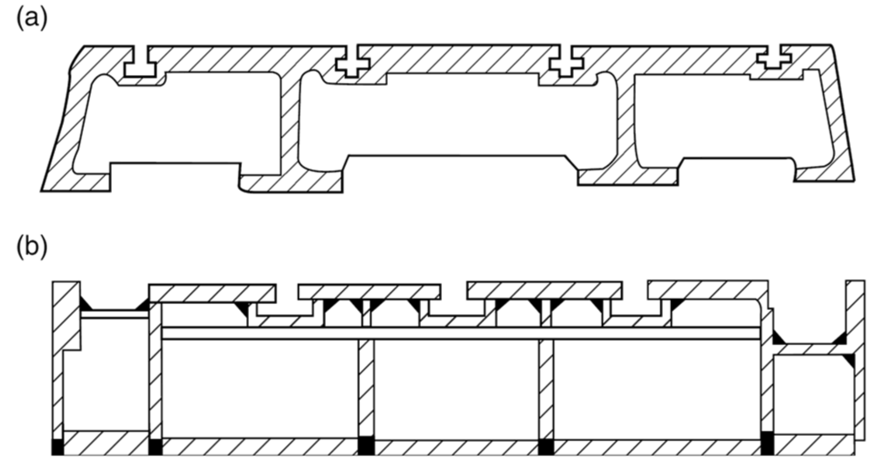


FIGURE 2.8 Lathe bed with raised rear guideways.

ساختار ماشین های ابزار

- Figure 2.9 shows typical cast and fabricated machine tool structures.
- A cast iron (CI) structure ensures the following advantages:
  - Better lubricating property (due to the presence of free graphite);
  - most suitable for beds in which rubbing is the main criterion
  - High compressive strength
  - Better damping capacity
  - Easily cast and machined

MACHINE TOOL STRUCTURES



Cast and fabricated structures: (a) cast and (b) welded machine tool bases.

MACHINE TOOL STRUCTURE: LIGHT- AND HEAVY-WEIGHT CONSTRUCTIONS

- Machine tool structures are classified according to their natural frequency as light- or heavy-weight construction.
- The natural frequency ω_0 of a machine tool can be described by:

$$\omega_0 = \sqrt{\frac{k}{m}}$$

k = structure static stiffness
m = mass

$$k = \frac{F}{\delta}$$

F = force (N)
δ = deflection (mm)

MACHINE TOOL STRUCTURE: LIGHT- AND HEAVY-WEIGHT CONSTRUCTIONS

- To avoid resonance and thus reduce the dynamic deflection of the machine tool structure, ω_0 should be far below or far above the exciting frequencies, which is equal to a multiple of the rotational speed of the machine.
- If the natural frequency of the machine structure is kept far below the speed working range of the machine tool then

$$\omega_0 < \text{exciting frequency}$$

$$\sqrt{\frac{k}{m}} < \text{exciting frequency}$$

MACHINE TOOL STRUCTURE: LIGHT- AND HEAVY-WEIGHT CONSTRUCTIONS

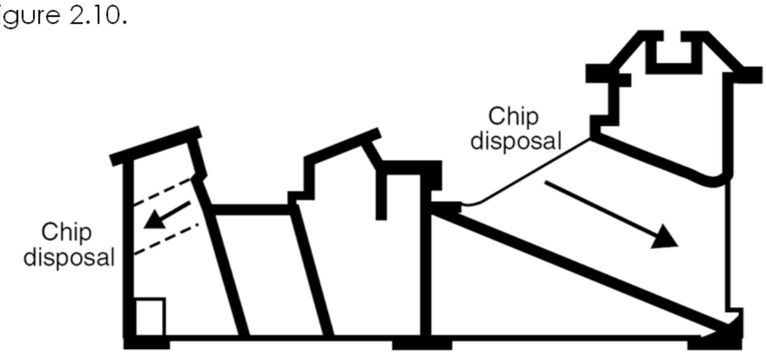
- This requirement is achieved by the increase of the mass m, which, in turn, leads to a heavyweight construction. On the other hand, lightweight constructions are made when

$$\omega_0 > \text{exciting frequency}$$

$$\sqrt{\frac{k}{m}} > \text{exciting frequency}$$

MACHINE TOOL STRUCTURE: LIGHT- AND HEAVY-WEIGHT CONSTRUCTIONS

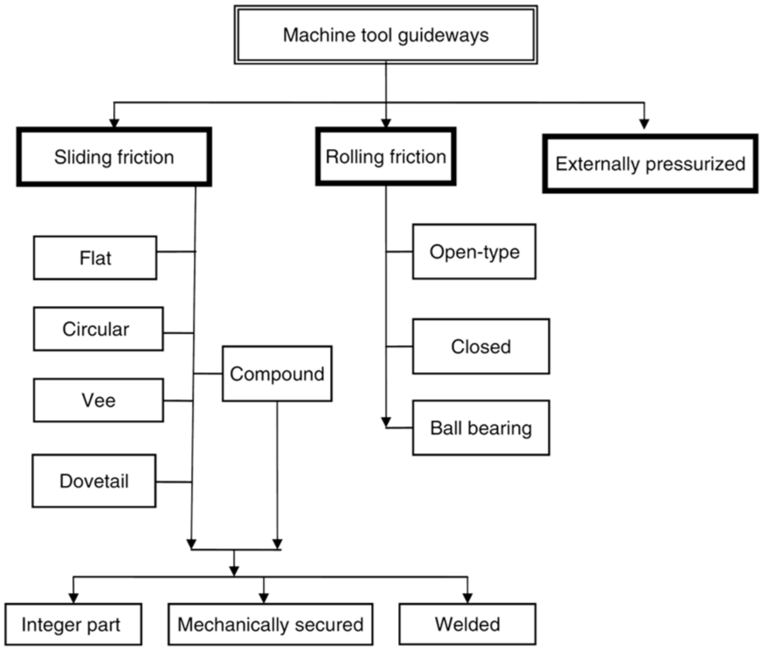
- Chip disposal, in the case of high-production machine tools, affects the construction of the machine tool frame as shown in Figure 2.10.



Chip disposal in a lathe bed.

MACHINE TOOL GUIDEWAYS

- Machining occurs as a result of a relative motion between the tool and the WP. Such a motion is a rotary, linear, or rectilinear one.
- Guideways are required to perform the necessary machine tool motion at a high level of accuracy under severe machining conditions.
- Generally guideways, therefore, control the movement of the different parts of the machine tool in all positions during machining and nonmachining times.
- Besides the accuracy requirements, ease of assembly, and economy in manufacturing guideways, the following features should be provided:
- ✓ Accessibility for effective lubrication
- ✓ Wear resistance, durability, and rigidity
- ✓ Possibility of wear compensation
- ✓ Restriction of motion to the required directions
- ✓ Proper contact all over the sliding area
- Guideways are classified as sliding friction, rolling friction, and externally pressurized (Figure 2.11).



MACHINE TOOL GUIDEWAYS: SLIDING FRICTION GUIDEWAYS

- Sliding friction guideways consist of any one of or a combination of the flat, vee, dovetail, and cylindrical guideway elements.
- Flat circular guideways are used for guiding the rotating table of the vertical turning and boring machines.
- Figure 2.12 shows the different types of guideways that are normally used to guide sliding parts in the longitudinal directions.
- Holding strips may be provided to prevent the moving part from lifting or tilling by the operational forces.
- Scraping and the introduction of thin shims are used for readjustments that may be required to compensate wear of the sliding parts.

MACHINE TOOL GUIDEWAYS: SLIDING FRICTION GUIDEWAYS

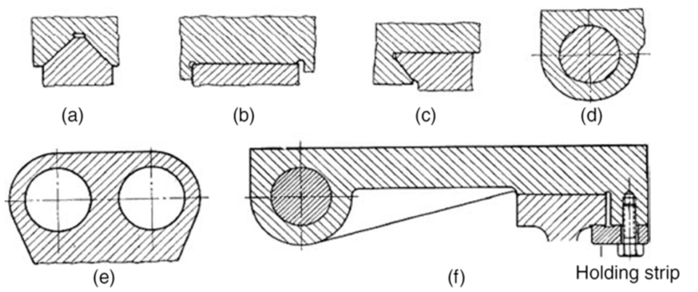


FIGURE 2.12 Types of guideways: (a) vee, (b) flat, (c) dovetail, (d) cylinder, (e) cylindrical–cylindrical, and (f) cylindrical–flat.

MACHINE TOOL GUIDEWAYS: SLIDING FRICTION GUIDEWAYS

- Vee-shaped guideways are either male or female type, which are self-adjusting under the weight of the guided parts.
- The combination of two vee guideways has an unfavorable effect on the machining accuracy and is limited to guideways of relatively small distance between the two vees.
- Circular vee guideways carry the operational loads and provide self location for the rotating table.
- Dovetail guideways, shown in Figure 2.12c, are used separately or in a combination of half dovetail and flat guideways.
- Cylindrical guides, shown in Figure 2.12d, are either male or female type that must be accurately manufactured. They require special devices to adjust their working clearances.
- The column of the drilling machine is a typical example of the male type, while the sleeve of the drilling machine spindle is a female type.
- The combinations of cylindrical guideways are shown in Figures 2.12e (cylindrical–cylindrical) and 2.12f (cylindrical–flat).

MACHINE TOOL GUIDEWAYS: SLIDING FRICTION GUIDEWAYS

- For the sliding surfaces, the bulk of the load is carried on the metal-to-metal contact.
- The load carried by the lubricating oil film is very small.
- The localized pressures cause elastic or plastic deformation to the supporting asperities of the surface, which in turn results in an instability of the sliding motion usually known as the stick–slip effect.
- This phenomenon can be reduced or eliminated by the use of proper lubricants or through the introduction of externally pressurized guideways.
- Friction condition and, consequently, the wear of the guideways are affected by
- 1. material properties of the fixed and moving element,
- 2. surface dimensions of the guideways,
- 3. acting pressure,
- 4. accumulation of dirt, chip, and wear debris.

MACHINE TOOL GUIDEWAYS: SLIDING FRICTION GUIDEWAYS

- When the machine parts rub together, loss of material from one or both surfaces occurs, which in turn results in a change of the designed dimensions and geometry of the guideways system.
- Wear of guideways may be caused by the cutting action of the hard particles (adhesive wear), which is often accompanied by the oxidation of the wear debris that leads to additional abrasive wear.
- Wear of guideways can be minimized by
- 1. minimizing the sliding surface roughness,
- 2. increasing the hardness of the sliding surfaces,
- 3. removing the abrasive wear particles from the guideways system
- 4. reducing the pressure acting on the guiding surfaces.

MACHINE TOOL GUIDEWAYS: SLIDING FRICTION GUIDEWAYS

- Guideways are equipped with devices for initially adjusting and periodically compensating the working clearance.
- Clearance adjustment is accomplished by using suitable metallic strips, as shown in Figure 2.13.
- Guideways may be an integral part of the machine tool or mechanically secured to the bed by fastening or welding.
- In the first arrangement, the bed and the guideway are made from the same
- material, and flame or induction hardening is employed upon the guiding surfaces.
- In the mechanically secured guideways, separate steel guideways are secured to the CI beds, as shown in Figure 2.14a.

MACHINE TOOL GUIDEWAYS: SLIDING FRICTION GUIDEWAYS

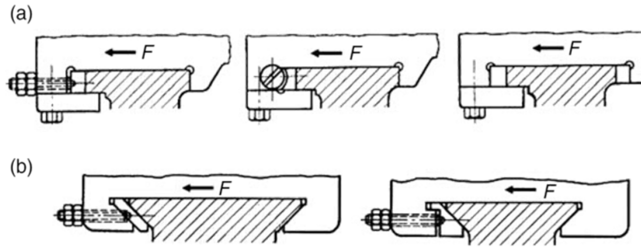
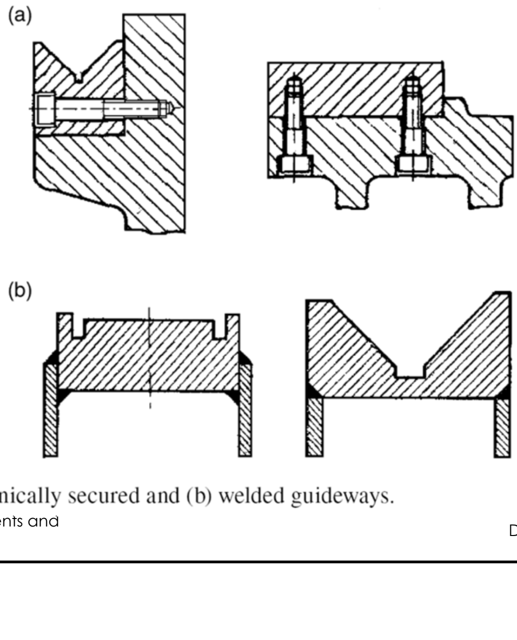


FIGURE 2.13 Wear compensation in guideways: (a) flat and (b) dovetail guideways. *F* is the side force actin on the carriage.

MACHINE TOOL GUIDEWAYS: SLIDING FRICTION GUIDEWAYS



(a) Mechanically secured and (b) welded guideways.

MACHINE TOOL GUIDEWAYS: ROLLING FRICTION GUIDEWAYS

- In rolling friction guideways, rollers, needles, or balls are inserted between the moving parts to minimize the frictional resistance, which is kept constant irrespective of the traveling speed.
- Rolling friction guideways find wide applications in numerically controlled and medium-size machine tools in which the setting accuracy is decisive.
- Their expensive manufacturing, complicated construction and the short life of the rolling elements create problems.
- Rolling friction guideways are either open or closed.
- The open type (Figure 2.15) is used when the load acts downward, which makes this type self-adjusting for wear in the guideways.
- In the closed type, wear compensation requires adjusting elements.
- For long strokes, recirculating rolling elements (as shown in Figure 2.16) or ball or roller bearing guideways (Figure 2.17) are used to shorten the length of the slider.

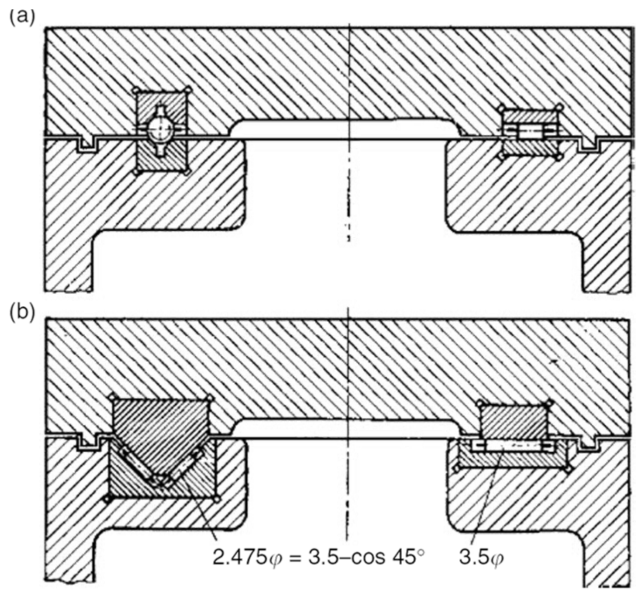


FIGURE 2.15 Open-type rolling friction guideways: (a) flat and (b) vee–flat guideways.

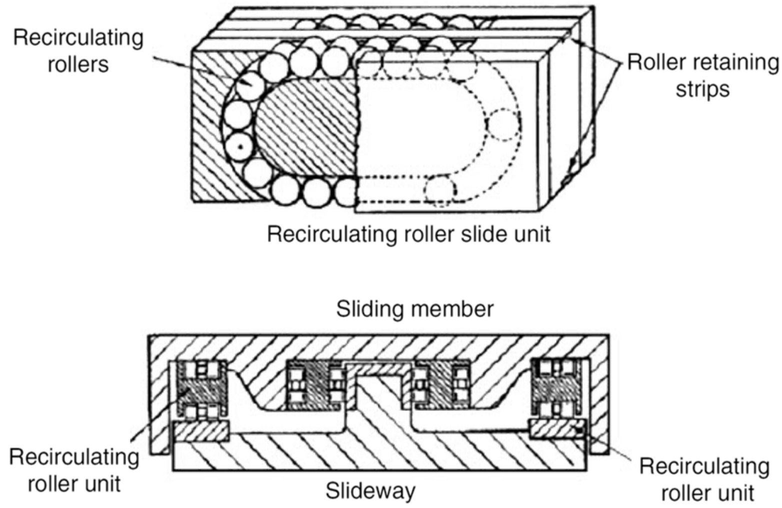


FIGURE 2.16 Recirculating rolling friction guideways.

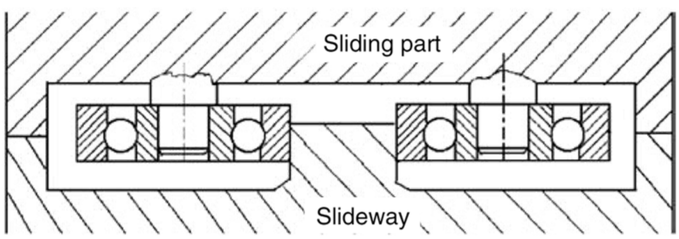


FIGURE 2.17 Ball bearing guideway.

MACHINE TOOL GUIDEWAYS: ROLLING FRICTION GUIDEWAYS

- Circular rolling friction guideways find applications in high-speed vertical lathes. The size and the distribution of the load on the rolling elements and the deformation of the guideways are affected by:
- 1. magnitude, distribution, and type of loading,
- 2. stiffness of the rolling elements,
- 3. manufacturing errors of the rolling elements,
- 4. form error of the guideways,
- 5. magnitude of preloading
- 6. stiffness of the table, bed, fixture, and WP.

MACHINE TOOL GUIDEWAYS:

EXTERNALLY PRESSURIZED GUIDEWAYS

- The load-carrying capacity and stiffness of ordinary lubricated guideways are excellent; however, their friction levels are undesirable.
- To overcome such a problem, externally pressurized guideways are used in which the sliding elements are separated by a thin film of pressurized fluid, as shown in Figure 2.18.
- Such an arrangement prevents contact between the sliding surfaces and hence avoids the occurrence of wear.
- The load-carrying capacity is independent of the sliding speed, and the reaction forces are distributed over the full bearing area.
- Externally pressurized guideways are ideal guideways in terms of stiffness, uniformity of travel, low friction, large damping, and better heat dissipation capacity.

MACHINE TOOL GUIDEWAYS:

EXTERNALLY PRESSURIZED GUIDEWAYS

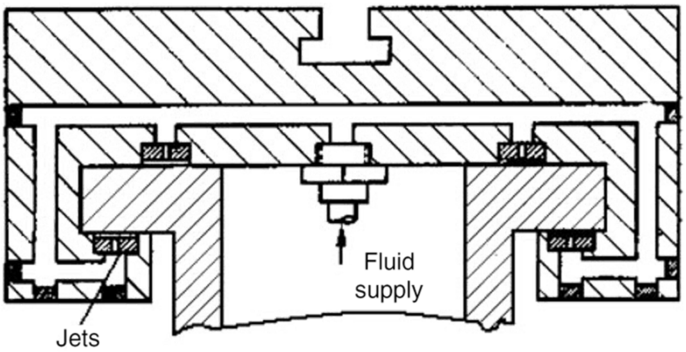


FIGURE 2.18 Externally pressurized guideways.

MACHINE TOOL GUIDEWAYS:

EXTERNALLY PRESSURIZED GUIDEWAYS

- Generally, the service properties of machine tool guideways can be improved by
- 1. providing favorable frictional conditions, which can be achieved by using
  - a. combined sliding and rolling guides,
  - b. proper lubricants and materials for guideways
  - c. hydrostatic ways with high-rigidity oil film and automatic control systems,
- 2. providing adequate protection of guideways,
- 3. using optimal cross-section of slideways,
- 4. using optimal surface finishes.

MACHINE TOOL SPINDLES

- Machine tool spindles are used to locate, hold, and drive the tool or the WP.
- These spindles possess a high degree of rigidity, rotational accuracy, and wear resistance.
- Spindles of the general purpose machine tools are subjected to heavier loads compared with precision ones.
- In the former class of spindles, rigidity is the main requirement; in the second, the manufacturing accuracy is of the prime consideration.
- Spindles are normally made hollow and provided with an internal taper at the nose end to accommodate the center or the shank of the cutting tool (Figure 2.19).

MACHINE TOOL SPINDLES

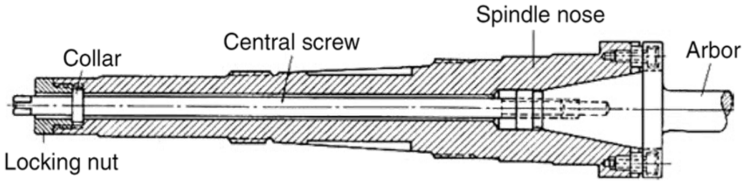


FIGURE 2.19 Typical milling machine spindle.

MACHINE TOOL SPINDLES

- A thread can be added at the nose end to fix a chuck or a face plate.
- Medium-carbon steel containing 0.5% C is used for making spindles in which hardening is followed by tempering to produce a surface hardness of about 40 Rockwell (HRC).
- Low-carbon steel containing 0.2% C can also be carburized, quenched, and tempered to produce a surface hardness of 50–60 HRC.
- Spindles for high-precision machine tools are hardened by nitriding, which provides a sufficient hardness with the minimum possible deformation.
- Manganese steel is used for heavy-duty machine tool spindles.

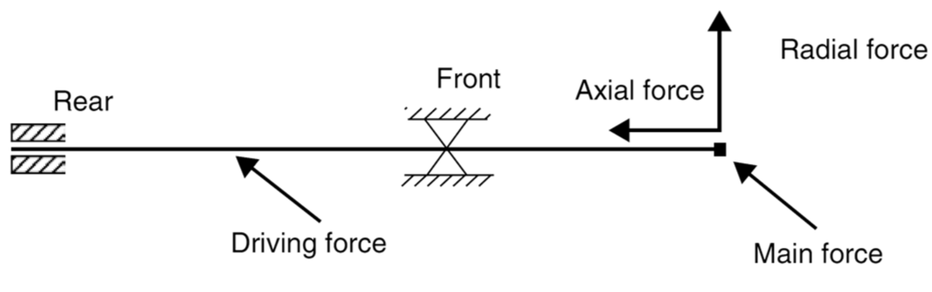
MACHINE TOOL SPINDLES: SPINDLE BEARINGS

- Generally, machine tool spindle bearings must provide the following requirements:
- 1. Minimum deflection under varying loads
- 2. Accurate running under loads of varying magnitudes and directions
- 3. Adjustability to obtain minimum axial and radial clearances
- 4. Simple and convenient assembly
- 5. Sufficiently long service
- 6. Maximum temperature variation throughout the speed ranges
- 7. Sufficient wear resistance

MACHINE TOOL SPINDLES: SPINDLE BEARINGS

- The forces acting on a machine tool spindle are the cutting force, which acts at the spindle nose, and the driving force, which acts in between the spindle bearings (Figure 2.20).
- The cutting force can be resolved into two components with respect to the spindle.
- The spindle bearings have to take radial and axial components of the cutting and driving forces.
- In this manner, when the machine tool spindle is mounted at two points, the bearing at one point takes the axial component besides the reaction of the radial component, while the other takes only the reaction of the radial component.
- The bearings that carry the axial component should prevent the axial movement of the spindle under the effect of the cutting and driving forces (fixed bearing).
- The other bearing (floating bearing) provides only a radial support and provides axial displacement due to differential thermal expansion of the spindle shaft and the housing.

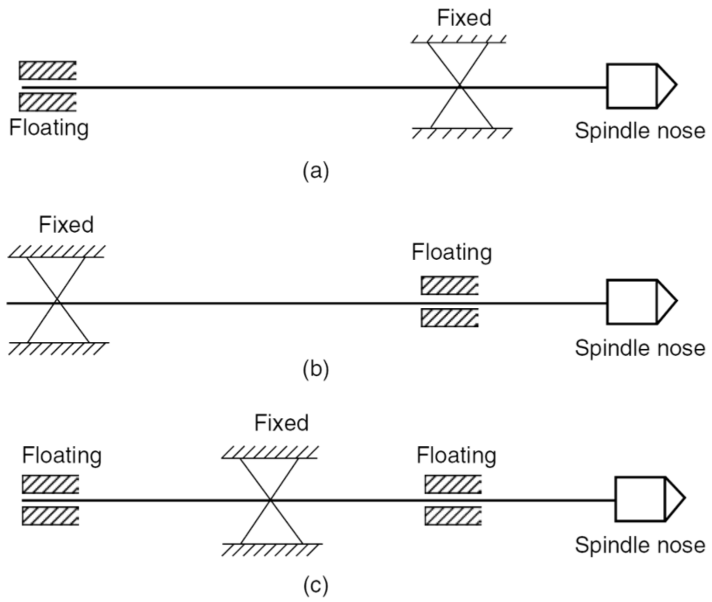
MACHINE TOOL SPINDLES: SPINDLE BEARINGS



Forces acting on machine tool spindles.

MACHINE TOOL SPINDLES: SPINDLE BEARINGS

- The arrangement shown in Figure 2.21a is used in most high-speed machine tools because the free length of the spindle (from nose to the fixed bearing) is limited, which minimizes nose deflection.
- Additionally, the effect of differential thermal expansion of the spindle and spindle housing acts toward the floating (rear) end, which in turn reduces the axial displacements of the spindle nose.
- Figure 2.22 shows typical spindle bearing mounting arrangements. Figure 2.23 presents a machine tool spindle with the fixed front bearing while the rear end axially slides at the outer race of the roller bearing.
- The various considerations in the selection of bearings are
- 1. direction of load relative to the bearing axial,
- 2. intensity of load,
- 3. speed of rotation,
- 4. thermal stability,
- 5. stiffness of the spindle shaft
- 6. class of accuracy of the machine.



Fixed and floating bearing arrangements: (a) fixed front, (b) fixed rear, and (c) fixed middle.

MACHINE TOOL SPINDLES: SPINDLE BEARINGS

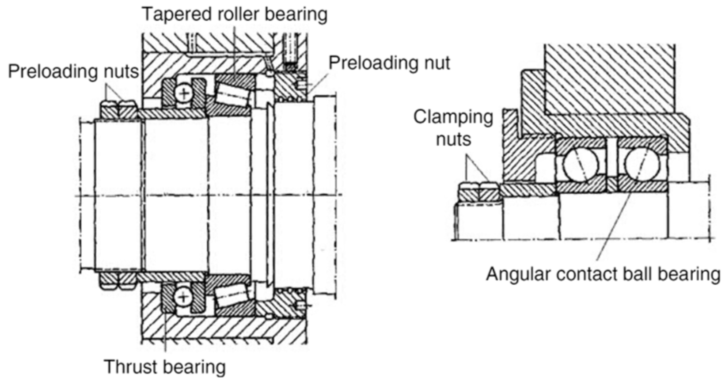


FIGURE 2.22 Typical spindle-bearing arrangements. (From Browne, J. W., *The Theory of Machine Tools, Book-1*, Cassell and Co. Ltd., London, 1965.)

MACHINE TOOL SPINDLES: SPINDLE BEARINGS

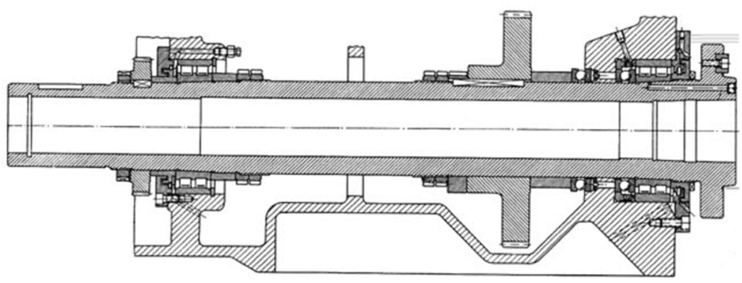


FIGURE 2.23 Typical machine tool spindle. (From Koenigsberger, F., *Berechnungen, Konstruktiosgrundlagen und Bauelemente spanender Werkzeugmaschinen*, Springer, Berlin, 1961. With permission.)

MACHINE TOOL SPINDLES:

SLIDING FRICTION SPINDLE BEARING

- Rolling bearings are used at a speed and diameter range of $n \cdot d \leq 2 \times 10^5$ where n is the spindle rotational speed in revolutions per minute and d is the diameter of the spindle in millimeters.
- At higher running speeds, the bearing life is reduced due to the gyratory action, especially in bearings that take combined loads.
- At high spindle speeds, as in case of grinding, sliding friction (journal) bearings that have high damping capacity compared with rolling bearings are used.
- Their load- carrying capacity increases as the spindle speed increases due to the hydrodynamic action created within the bearing.
- For an optimum performance, the radial clearance between journal and bearing should be properly maintained, as it affects bearing friction, load-carrying capacity, and the efficiency of heat dissipation of the bearing.

MACHINE TOOL SPINDLES:

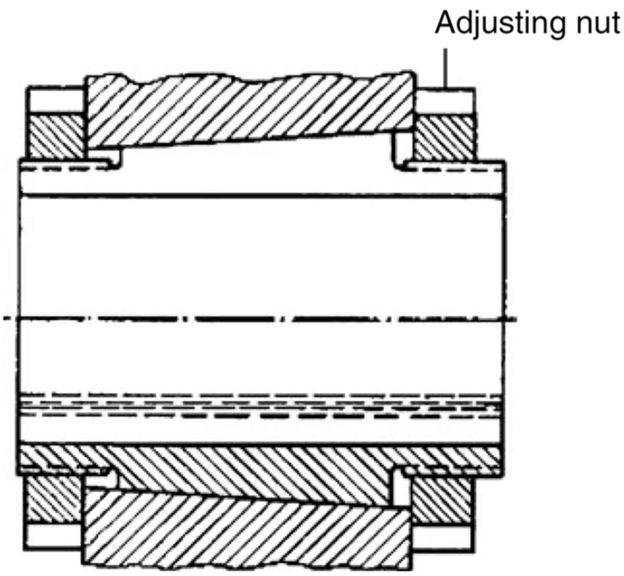
SLIDING FRICTION SPINDLE BEARING

- The main types of sliding friction bearings include the following:
- 1. Sliding bearing with radial play adjustment using segments that can be adjusted radically to control the clearance.
- 2. Bearing with axial play adjustment, in which a bush with a cylindrical bore and external taper has a slot along its length and is made to fi t in a taper hole in the housing. When the bush slides axially, through two opposing nuts, on the two ends of the bush, radial play can be finely adjusted and controlled (Figure 2.25).

MACHINE TOOL SPINDLES:

SLIDING FRICTION SPINDLE BEARING

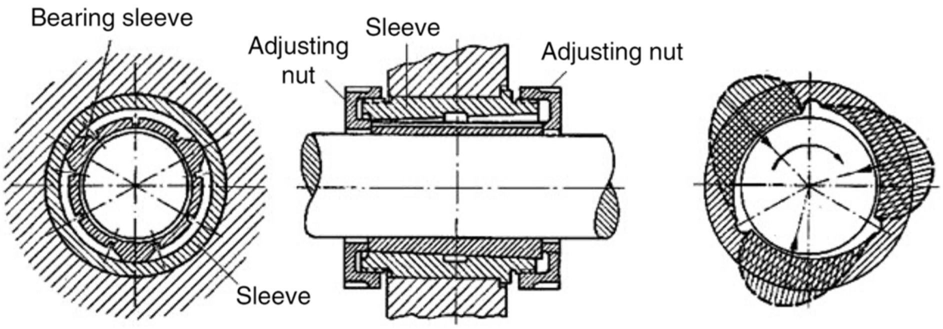
- 3. Mackensen bearing is used in highly accurate machine tool spindles, running at extremely high speeds, under limited applied load. As shown in Figure 2.26, an elastic bearing bush is supported at three points in the housing. This bush has nine equally spaced axial slots along its circumference. When the shaft is running, the bush deforms into a triangular shape, and three wedge-shaped oil pockets are formed, which constitute the load-carrying parts of the bearing.
- 4. Hydrodynamic multipad spindle bearing of high radial and axial thrust capacity, high stiffness, and practically no clearance during operation.



Sliding friction bearing.

MACHINE TOOL SPINDLES:

SLIDING FRICTION SPINDLE BEARING



26 Mackensen bearing.

MACHINE TOOL SPINDLES:

SLIDING FRICTION SPINDLE BEARING

- Sliding bearing materials should have high compressive strength to withstand the bearing pressure, low coefficient of friction, and high thermal conductivity.
- It should possess high wear resistance and maintain a continuous oil film.
- The various sliding bearing metals include:

1. copper base bearing metals (85% Cu, 10% Sn, 5% Zn), which are used for heavy loads,
2. tin base bearing (babbit) metals (85% Sn, 10% Sb, 5% Cu), which are used for higher loads,
3. lead base bearing metals (10–30% Pb, 10–15% Sb, and the rest is copper), which are used for light loads,
4. cadmium base bearing metals (95% Cd and a very small amount of iridium) which have higher compressive strength and more favorable properties at higher temperatures.

MACHINE TOOL DRIVES

- To obtain a machined part by a machine tool, coordinated motions must be imparted to its working members.
- These motions are either primary (cutting and feed) movements, which removes the chips from the WP or auxiliary motions that are required to prepare for machining and ensure the successive machining of several surfaces of one WP or a similar surface of different WPs.
- Principal motions may be either rotating or straight reciprocating.
- In some machine tools, this motion is a combination of rotating and reciprocating motions.
- Feed movement may be continuous (lathes, milling machine, drilling machine) or intermittent (planers).
- As shown in Figure 2.27, stepped motions are obtained using belting or gearing.
- Stepless speeds are achieved by mechanical, hydraulic, and electrical methods.

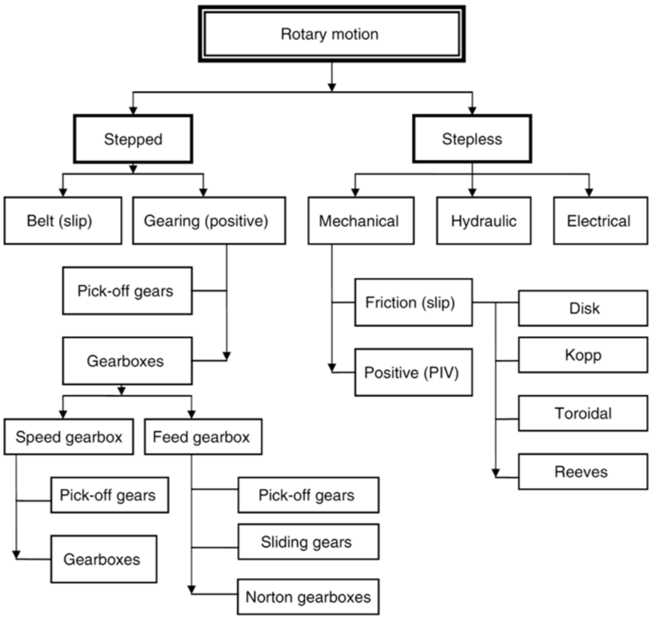


FIGURE 2.27 Classification of transmission of rotary motion.

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES: Belting

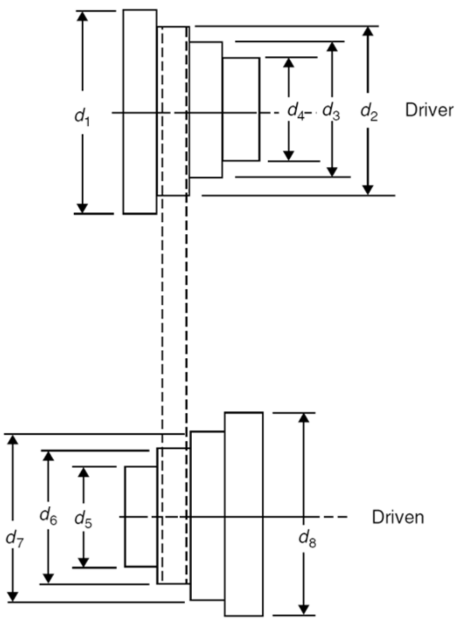
- The belting system, shown in Figure 2.28, is used to produce four running rotational speeds n_1, n_2, n_3, and n_4.
- It is cheap and absorbs vibrations.
- It has the limitation of the low-speed changing, slip, and the need for more space.
- Based on the driver speed n_1, the following speeds can be obtained in a decreasing order:

$$n_1 = n\frac{d_1}{d_5}$$

$$n_2 = n\frac{d_2}{d_6}$$

$$n_3 = n\frac{d_3}{d_7}$$

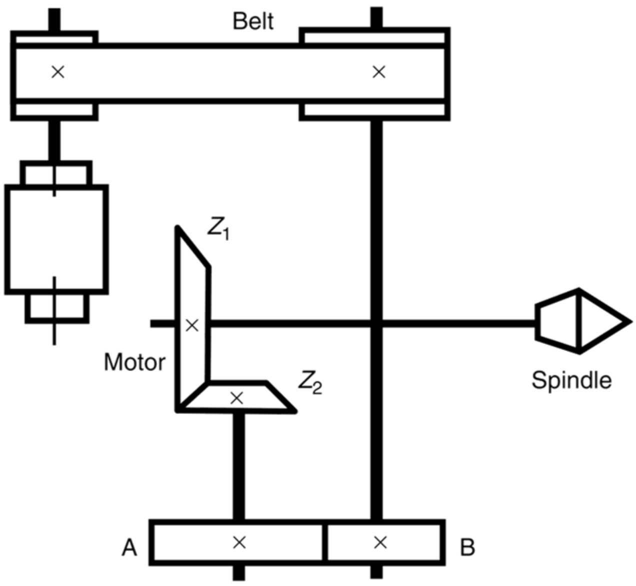
- This type is commonly used for grinding and bench-type drilling machines.



Belting transmission.

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES: Pick-Off Gears

- Pick-off gears are used for machine tools of mass and batch production automatic and semiautomatic machines, special-purpose machines, and so on) when the changeover from job to job is comparatively rare.
- Pick-off gears may be used in speed or feed gearboxes.
- As shown in Figure 2.29, the change of speed is achieved by setting gears A and B on the adjacent shafts.
- As the center distance is constant, correct gear meshing occurs if the sum of teeth of gears A and B is constant.



Pick-off gears.

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES: Gearboxes

- Machine tools are characterized by their large number of spindle speeds and feeds to cope with the requirements of machining parts of different materials and dimensions using different types of cutting tool materials and geometries.
- The cutting speed is determined on the bases of the cutting ability of the tool used, surface finish required, and economical considerations.
- A wide variety of gearboxes utilize sliding gears or friction or jaw coupling.
- The selection of a particular mechanism depends on the purpose of the machine tool, the frequency of speed change, and the duration of the working movement.

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES: Gearboxes

- The advantage of a sliding gear transmission is that it is capable of transmitting higher torque and is small in radial dimensions.
- Among the disadvantages of these gearboxes is the impossibility of changing speeds during running.
- Clutch-type gearboxes require small axial displacement needed for speed changing, less engagement force compared with sliding gear mechanisms, and therefore can employ helical gears.

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES: Gearboxes

- The extreme spindle speeds of a machine tool main gearbox n_{max} and n_{min} can be determined by

$$n_{max} = \frac{1000V_{max}}{\pi d_{min}}$$

$$n_{min} = \frac{1000V_{min}}{\pi d_{max}}$$

V_{max} = maximum cutting speed (m/min) used for machining the most soft and machinable material with a cutting tool of the best cutting property

V_{min} = minimum cutting speed (m/min) used for machining the hardest material using a cutting tool of the lowest cutting property or the necessary speed for thread cutting

d_{max}, d_{min} = maximum and minimum diameters (mm) of WP to be machined

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES: Gearboxes

- The speed range R_n becomes

$$R_n = \frac{n_{max}}{n_{min}} = \frac{v_{max}}{v_{min}} \cdot \frac{d_{max}}{d_{min}} = R_v \cdot R_d$$

R_v = cutting speed range

R_d = diameter range

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES: Gearboxes

- In case of machine tools having rectilinear main motion (planers and shapers), the speed range R_n is dependent only on R_v.
- For other machine tools, R_n is a function of R_v and R_d, large cutting speeds and diameter ranges are required.
- Generally, when selecting a machine tool, the speed range R_n is increased by 25% for future developments in the cutting tool materials.
- Table 2.4 shows the maximum speed ranges in modern machine tools.

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES: Gearboxes

TABLE 2.4
Speed Range for Different Machine Tools

Machine	Range
Numerically controlled lathes	250
Boring	100
Milling	50
Drilling	10
Surface grinding	4

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES:

Stepping of Speeds According to Arithmetic Progression

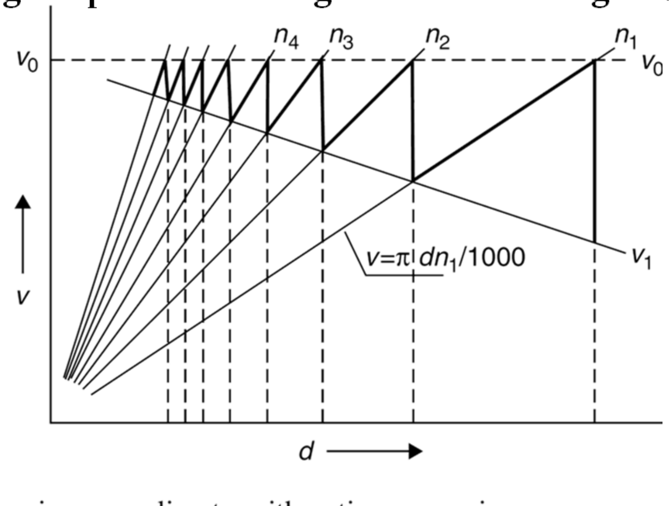
- Let n_1, n_2, … , n_z be arranged according to arithmetic progression. Then

$$n_1 - n_2 = n_3 - n_2 = \text{constant}$$

- The sawtooth diagram in such a case is shown in Figure 2.30. Accordingly, for an economical cutting speed v_0, the lowest speed v_l is not constant; it decreases with increasing diameter.
- Therefore, the arithmetic progression does not permit economical machining at large diameter ranges.
- The main disadvantage of such an arrangement is that the percentage drop from step to step δ_n decreases as the speed increases.
- Thus the speeds are not evenly distributed and more concentrated and closely stepped, in the small diameter range than in the large one.
- Stepping speeds according to arithmetic progression are used in Norton gearboxes or gearboxes with a sliding key when the number of shafts is only two.

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES:

Stepping of Speeds According to Arithmetic Progression



Speed stepping according to arithmetic progression.

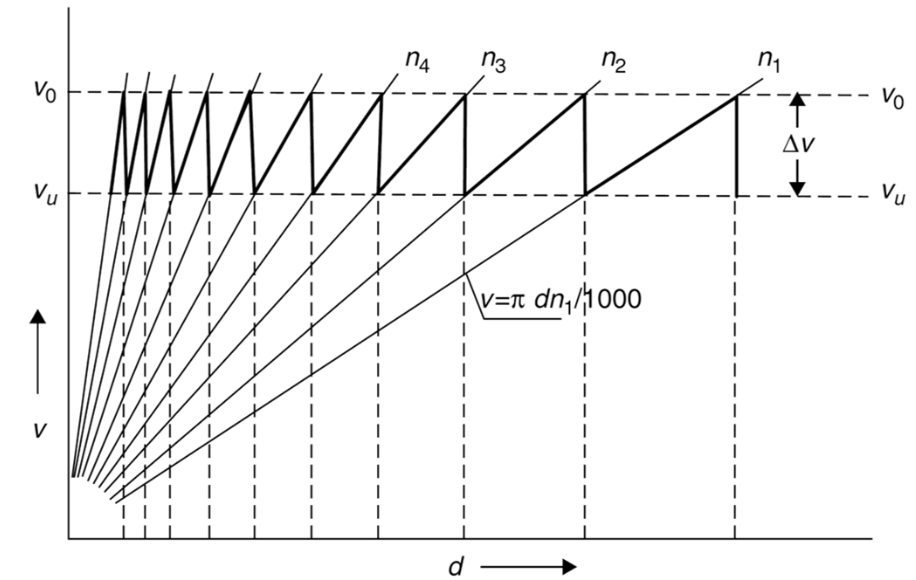
MACHINE TOOL DRIVES: STEPPED SPEED DRIVES:

Stepping of Speeds According to Geometric Progression

- As shown in Figure 2.31, the percentage drop from one step to the other is constant, and the absolute loss of economically expedient cutting speed Δv is constant all over the whole diameter range.
- The relative loss of cutting speed $\Delta v_{max}/v_0$ is also constant.
- Geometric progression, therefore, allows machining to take place between limits v_0 and v_u independent of the WP diameter, where v_0 is the economical cutting speed and v_u is the allowable minimum cutting speed.
- Now suppose that n_1, n_2, n_3, … ,n_z are the spindle speeds. According to the geometric progression,

$$\frac{n_2}{n_1} = \frac{n_3}{n_2} = \varphi$$

- where φ is the progression ratio.



Speed stepping according to geometric progression.

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES:

Stepping of Speeds According to Geometric Progression

- The spindle speeds can be expressed in terms of the minimal speed n_1 and progression ratio φ.

$$\begin{array}{ccccc} n_1 & n_2 & n_3 & n_4 & n_z \\ n_1 & n_1\varphi & n_1\varphi^2 & n_1\varphi^3 & n_1\varphi^{z-1} \end{array}$$

- Hence, the maximum spindle speed n_z is given by

$$n_z = n_1\varphi^{z-1}$$

- where z is the number of spindle speeds, therefore,

$$\varphi = \sqrt[z-1]{\frac{n_z}{n_1}} = \sqrt[z-1]{R_n} = (R_n)^{1/(z-1)}$$

- from which

$$z = \frac{\log R_n}{\log \varphi} + 1$$

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES:

Stepping of Speeds According to Geometric Progression

- Progression ratios are standardized according to ISO standards in such a way as to allow standard speeds and feeds, including full load induction motor speeds of 2800, 1400, and 710 rpm to be used.
- Table 2.5 shows the standard values of φ according to ISO/R229. Similarly, machine tool speeds are standardized according to ISO/R229.
- Such speeds enable the direct drive of machine tool spindles using induction motors with changing poles.
- The full load speeds of induction motors are 236, 280, 322, 472, 200, 710, 920, 1400, and 2800 rpm.
- Tables 2.6 and 2.7 show the standard speeds and feeds
- according to ISO/R229.

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES:

Stepping of Speeds According to Geometric Progression

TABLE 2.5
Standard Values of Progression Ratio φ According to ISO/R229 and Deutsches Institüt für Normung (DIN) 323

Basic and Derived Series	Standard Value	Accurate Value	Percentage Drop	Application
R20	$20\sqrt{10} = 1.12$	1.1221	10	Seldom used
R20/2	$(20\sqrt{10})^2 = 1.26$	1.258	20	Machines of large z
R20/3	$(20\sqrt{10})^3 = 1.4$	1.4125	30	Machines of large R_n
R20/4	$(20\sqrt{10})^4 = 1.6$	1.5849	40	and small z
R20/6	$(20\sqrt{10})^6 = 2.0$	1.9953	50	Drilling machines

Note: z, Number of speeds; R_n, speed range.

TABLE 2.6
Standard Speeds According to ISO/R229 and DIN 804

	Basic Series	Derived Series										
Accurate Value (rpm)	R20	R20/2	R20/3			R20/4 1400–800		R20/6 2800			Limiting Values	Considering 2% Mechanical Tolerance
	$\varphi = 1.12$	$\varphi = 1.25$	$\varphi = 1.4$			$\varphi = 1.6$		$\varphi = 2.0$			−2%	+2%
100	100										98	102
112.2	112	112	11.2				112	11.2			110	114
162.89	125			125							123	128
141.25	140	140			1400	140				1400	138	144
158.49	160		16								155	162
177.83	180	160		180			180		180		174	181
199.52	200				2000						193	204
223.87	224	224	22.4			224		22.4			219	228
251.19	250			250							246	256
281.84	280	280			2800		280			2800	276	287
316.23	315		31.5								310	323
854.81	355	355		355		355			355		348	368
398.11	400				4000						390	406
446.68	450	450	45				450	45			448	456
501.19	500			500							491	511
562.34	560	560			5600	560				5600	551	574
630.96	630		63								618	643
707.95	710	710		710			710		710		694	722
794.33	800				8000						778	810
891.25	900	900	90			900		90			873	909
1000	1000			1000							980	1020

TABLE 2.7
Standard Feeds According to ISO/R229 and DIN 803

			Nominal Values					
R20	**R20/2**		**R20/3 ...1...**		**R20/4**		**R20/6 ...1...**	
$\varphi = 1.12$	$\varphi = 1.25$		$\varphi = 1.4$		$\varphi = 1.6$		$\varphi = 2.0$	
1.00	1.0		1.0		1.0		1.0	
1.12				11.2				
1.25	1.25	0.125				0.125		
1.40			1.4					
1.60	1.6			16	1.6			16
1.80		0.18						
2.00	2.0		2.0				2.0	
2.24				20				
2.50	2.5	0.25			2.5	0.25		
2.80			2.8					
3.15	3.15			31.5				31.5
3.55		0.355						
4.00	4.0		4.0		4		4.0	
4.50				45				
5.00	5.0	0.5				0.5		
5.60			5.6					
6.30	6.3			63	6.3			63
7.10		0.71						
8.00	8.0		8.0				8.0	
9.00				90				
10.00	10.0		1000		10			

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES:

Stepping of Speeds According to Geometric Progression

- **Illustrative Example**
- The following speeds form a geometric progression. Find the progression ratio and the percentage increase in the speed series.

n_1 (rpm)	n_2 (rpm)	n_3 (rpm)	n_4 (rpm)	n_5 (rpm)	n_6 (rpm)
14	18	22.4	28	35.2	45

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES:

Stepping of Speeds According to Geometric Progression

- *Solution*

$$\varphi = \frac{n_2}{n_1} = \frac{18}{14} = 1.25$$

- *Or*

$$\varphi = \sqrt[5]{\frac{45}{14}} = 1.25$$

- The percentage increase in speed δ_n

$$\delta_n = \frac{n_2 - n_1}{n_1} = \frac{\varphi n_1 - n_1}{n_1} = (\varphi - 1) \times 100$$

$$\delta_n = (1.25 - 1) \times 100 = 25\%$$

MACHINE TOOL DRIVES: STEPPED SPEED DRIVES:

Stepping of Speeds According to Geometric Progression

- **Illustrative Example**
- Given n_1 = 2.8 rpm, n_z = 31.50 rpm, and φ = 1.41, calculate the speed range R_n and the number of speeds z.
- Solution

$$R_n = \frac{n_z}{n_1} = \frac{31.50}{2.8} = 11.2$$

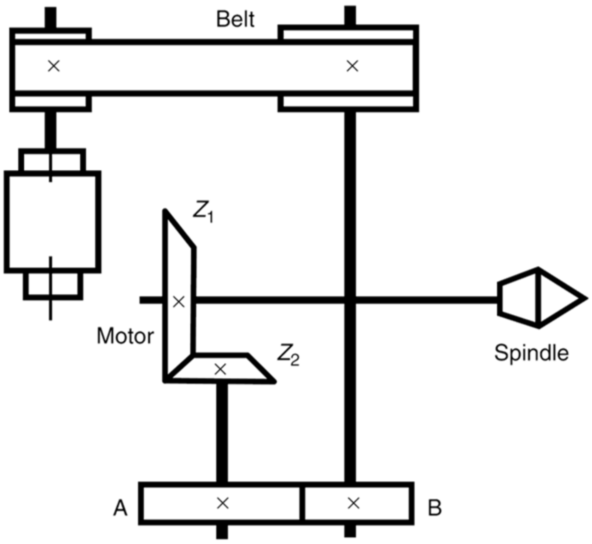
$$\varphi = (R_n)^{1/(z-1)} \qquad z = \frac{\log R_n}{\log \varphi} + 1$$

$$z = \frac{\log 11.2}{\log 1.41} + 1 = 8$$

MACHINE TOOL DRIVES:

STEPPED SPEED DRIVES: Feed Gearboxes

- Feed gearboxes are designed to provide the feed rates required for the machining operation.
- The values of feed rates are determined by the specified surface finish, tool life, and the rate of material removal.
- The classification of feed gearboxes according to the type of mechanism used to change the rate of feed is as follows:
- 1. Feed gearboxes with pick-off gears. Used in batch-production machine tools with infrequent changeover from job to job, such as automatic, semiautomatic, single-purpose, and special-purpose machine tools. These gearboxes are simple in design and are similar to those used for speed changing (Figure 2.29).



Pick-off gears.

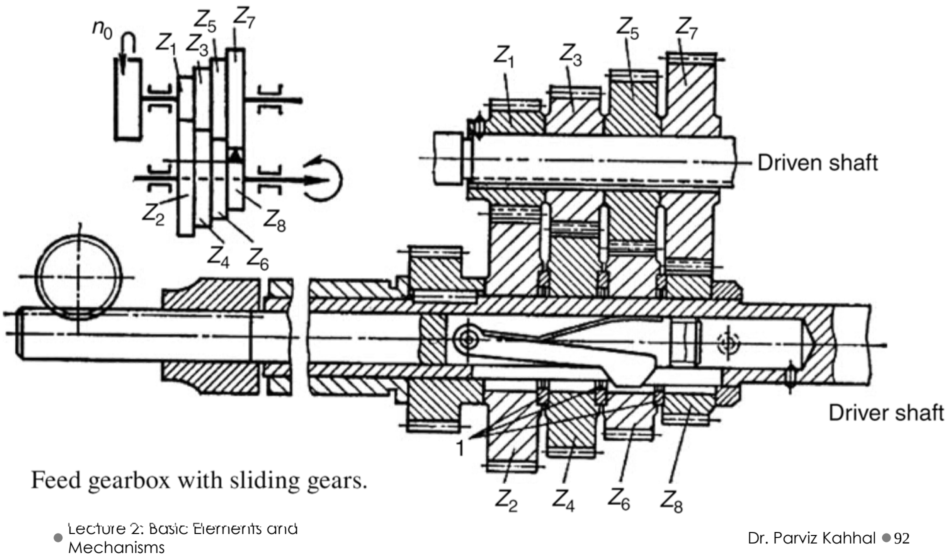
MACHINE TOOL DRIVES:

STEPPED SPEED DRIVES: Feed Gearboxes

- 2. Feed gearboxes with sliding gears. These gearboxes are widely used in general-purpose machine tools, transmit high torques, and operate at high speeds. Figure 2.36 shows a typical gearbox that provides four different ratios. Accordingly, gears Z2, Z4, Z6, and Z8 are keyed to the drive shaft and mesh, respectively, with gears Z1, Z3, Z5, and Z7, which are mounted freely on the driven key shaft. The sliding key engages any gear on the driven shaft. The engaged gear transmits the motion to the driven shaft while the rest of the gears remain idle.
- The main drawbacks of such feed boxes are the power loss and wear occurring due to the rotation of idle gears and insufficient rigidity of the sliding key shaft. Feed boxes with sliding gears are used in small- and medium-size drilling machines and turret lathes.

MACHINE TOOL DRIVES:

STEPPED SPEED DRIVES: Feed Gearboxes



Feed gearbox with sliding gears.

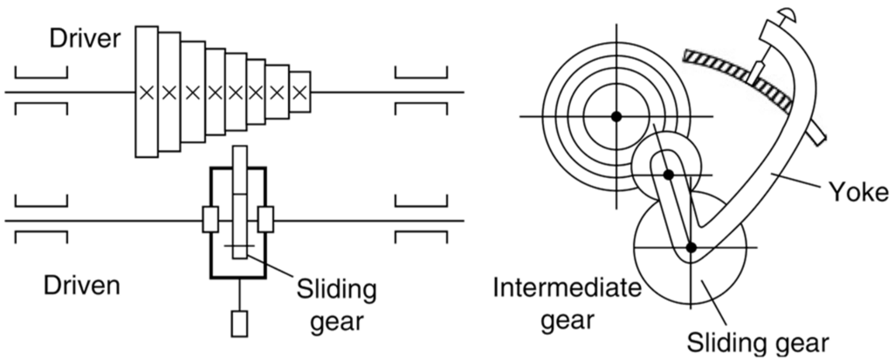
MACHINE TOOL DRIVES:

STEPPED SPEED DRIVES: Feed Gearboxes

- 3. Norton gearboxes. These gearboxes provide an arithmetic series of feed steps that is suitable for cutting threads and so are widely used in engine lathe feed gearboxes as shown in Figure 2.37.

MACHINE TOOL DRIVES:

STEPPED SPEED DRIVES: Feed Gearboxes



Norton gearbox.

MACHINE TOOL DRIVES:STEPPED SPEED DRIVES:

Preselection of Feeds and Speeds

- Preselection mechanisms in machine tools are used to select the speeds and feeds for the next machining operation during the machining time of the current operation. Once the current operation is finished, the selected speed and feed are automatically switched on with the press of a button.
- The main advantage of such a system in machine tools is to save the significant secondary time normally used for selecting the speeds and feeds at the end of each machining operation.
- Consequently, the total production time is reduced. The adoption of preselection mechanisms is justified whenever the speeds and feeds of the machine tool are frequently changed.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives

- Infinitely variable speed (stepless) drives provide output speeds, forming infinitely variable ratios to the input ones.
- Such units are used for main as well as feed drives to provide the most suitable speed or feed for each job, thereby reducing the machining time.
- They also enable machining to be achieved at a constant cutting speed, which leads to an increased tool life and ensures uniform surface finish.
- The easy and smooth changing of the speed or feed, without stopping the machine, results in an appreciable reduction in the production time that raises the productivity of the machine tool.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives

- Stepless speed drives may be mechanical, hydraulic, or electric.
- The selection of the suitable drive depends on the purpose of the machine tool, power requirements, speed range ratio, mechanical characteristics of the machining operation, and cost of the variable speed unit.
- In most stepless drives, the torque transmission is not positive. Their operation involves friction and slip losses.
- However, they are more compact, less expensive, and quieter in operation than the stepped speed control elements.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives

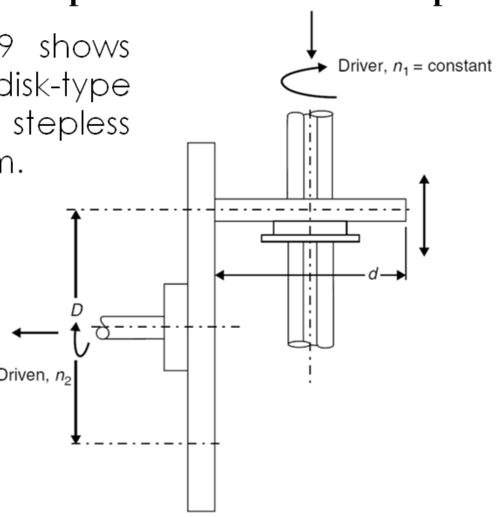
- Mechanical stepless drives include the following types:

1. Friction Stepless Drive
2. Kopp Variator
3. Toroidal and Reeves Mechanisms
4. Positive Infi nitely Variable Drive

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Friction Stepless Drive

- Figure 2.39 shows the disk-type friction stepless mechanism.



MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Friction Stepless Drive

- Accordingly, the drive shaft rotates at a constant speed n_1 as well as the friction roller of diameter d.
- The output speed of the driven shaft rotates at a variable speed n_2 that depends on the instantaneous diameter D.
- Because

$$n_1 d = n_2 D$$

- hence

$$n_2 = n_1 \frac{d}{D}$$

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Friction Stepless Drive

- The diameter ratio d/D can be varied in infinitely small steps by the axial displacement of the friction roller.
- If the friction force between the friction roller and the disk is F,

$$F = \frac{\text{input torque } (T_1)}{\text{input radius } (d/2)} = \frac{\text{output torque } (T_2)}{\text{output radius } (D/2)}$$

- If the power, contact pressure, transmission force, and efficiency are constant, the output torque T_2 is inversely proportional to the speed of the output shaft n_2.

$$T_2 \ \alpha \ T_1 \frac{n_1}{n_2}$$

- Due to the small contact area, a certain amount of slip occurs, which makes this arrangement suitable for transmitting small torques and is limited to reduction ratios not more than 1:4.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Kopp Variator

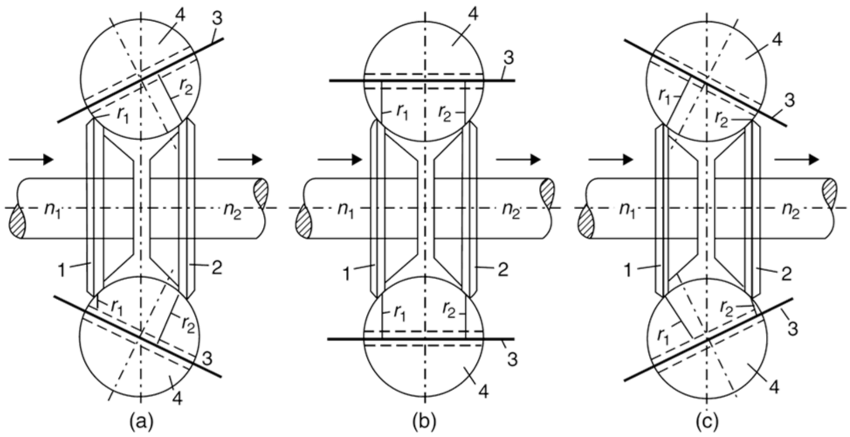


FIGURE 2.40 Kopp stepless speed mechanism: (a) $n_2 < n_1$, (b) $n_2 = n_1$, and (c) $n_2 > n_1$.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Kopp Variator

- In the Kopp variator, shown in Figure 2.40, the drive balls (4) mounted on inclinable axes (3) run in contact with identical, effective radii $r_1 = r_2$, and drive cones (1 and 2) are fixed on coaxial input and output shafts.
- When the axes of the drive balls (3) are parallel to the drive shaft axes, the input and output speeds are the same.
- When they are tilted, r_1 and r_2 change, which leads to the increase or decrease of the speed.
- Using Kopp mechanism, a speed range of 9:1, efficiency of higher than 80% and 0.25–12 hp capacity are obtainable.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Toroidal and Reeves Mechanisms

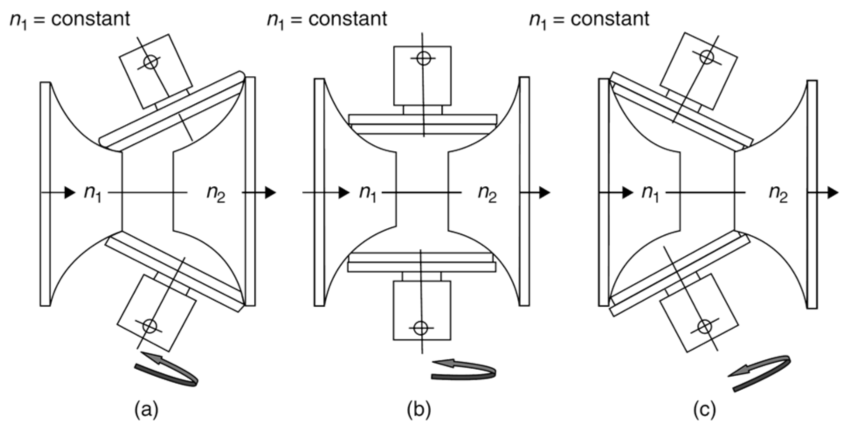
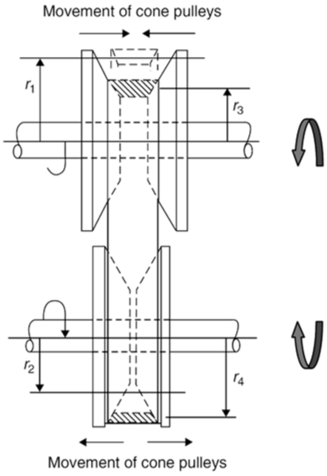


FIGURE 2.41 Toroidal stepless speed transmission: (a) $n_2 < n_1$, (b) $n_2 = n_1$, and (c) $n_2 > n_1$.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Toroidal and Reeves Mechanisms



Reeves variable speed transmission.

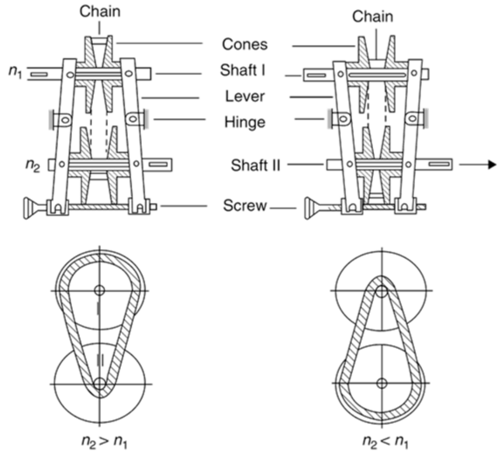
MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Toroidal and Reeves Mechanisms

- Figure 2.42 shows the Reeves variable speed transmission, which consists of a pair of pulleys connected by a V-shaped belt; each pulley is made up of two conical disks.
- These disks slide equally and simultaneously along the shaft and rotate with it. To adjust the diameter of the pulley, the two disks on the shaft are made to approach each other so that the diameter is increased or decreased.
- The ratio of the driving diameter to the driven one can be easily changed and, therefore, any desired speed can be obtained without stopping the machine.
- Drives of this type are available with up to 8:1 speed range and 10 hp capacity.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Positive Infinitely Variable Drive



Positive infinitely variable drive.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Positive Infinitely Variable Drive

- Figure 2.43 shows a positive torque transmission arrangement that consists of two chain wheels, each of which consists of a pair of cones that are movable along the shafts in the axial direction.
- The teeth of the chain wheels are connected by a special chain. By rotating the screw, the levers get moved thus changing the location of the chain pulleys, and hence the speed of rotation provides a speed ratio of up to 6 and is available with power rating up to 50 hp.
- The use of infinite variable speed units in machine tool drives and feed units is limited by their higher cost and lower efficiency or speed range.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Electrical Stepless Speed Drive

- Figure 2.44 shows the Leonard set, which consists of an induction motor that drives the direct current generator and an exciter (E).
- The dc generator provides the armature current for the dc motor, and the exciter provides the field current; both are necessary for the dc motors that drive the machine tool.
- The speed control of the dc motor takes place by adjusting both the armature and the field voltages by means of the variable resistances A and F, respectively.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Electrical Stepless Speed Drive

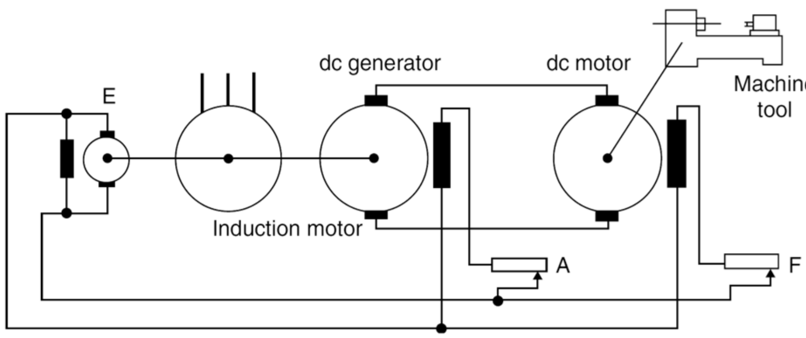


FIGURE 2.44 Leonard set (electrical stepless speed drive).

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Electrical Stepless Speed Drive

- By varying the resistance A, the terminal voltage of the dc generator and hence the rotor voltage of the dc motor can be adjusted between zero and a maximum value.
- The Leonard set has a limited efficiency: it is large, expensive, and noisy.
- Nowadays, dc motors and thyrestors that permit direct supply to the dc motors from an alternating current (ac) mains are available and, therefore, the Leonard set can be completely eliminated.
- Thyrestor feed drives can be regulated such that the system offers infinitely variable speed control.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Hydraulic Stepless Speed Drive

- The speeds of machine tools can be hydraulically regulated by controlling the oil discharge circulated in a hydraulic system consisting of a pump and hydraulic motor, both of the vane type, as shown in Figure 2.45.
- This is achieved by changing either the eccentricity of the pump e_p or the eccentricity of the hydraulic motor e_m or both.
- The vane pump running approximately at a constant speed delivers the pressurized oil to the vane type hydraulic motor, which is coupled to the machine tool spindle.
- To change the direction of rotation of the hydraulic motor, the reversal of the pump eccentricity is preferred.
- Speed control in hydraulic circuits can be accomplished by throttling the quantity of fluid flowing into or out of the hydrocylinders or hydromotor.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Hydraulic Stepless Speed Drive

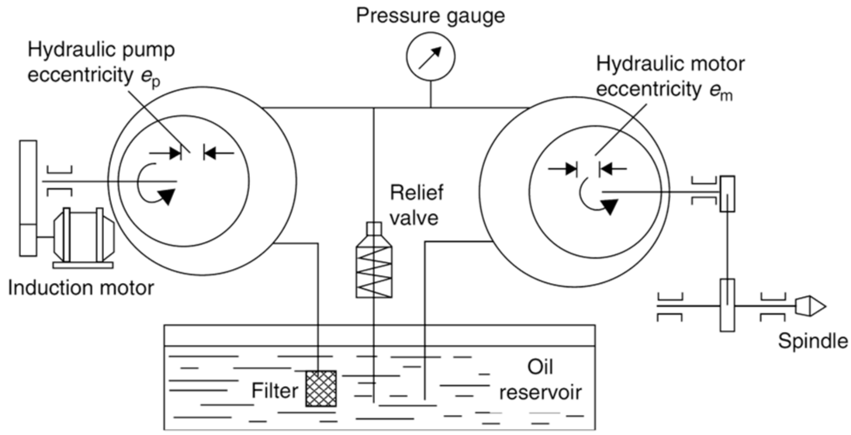


FIGURE 2.45 Hydraulic stepless speed drive.

MACHINE TOOL DRIVES:STEPLESS SPEED DRIVES:

Mechanical Stepless Drives: Hydraulic Stepless Speed Drive

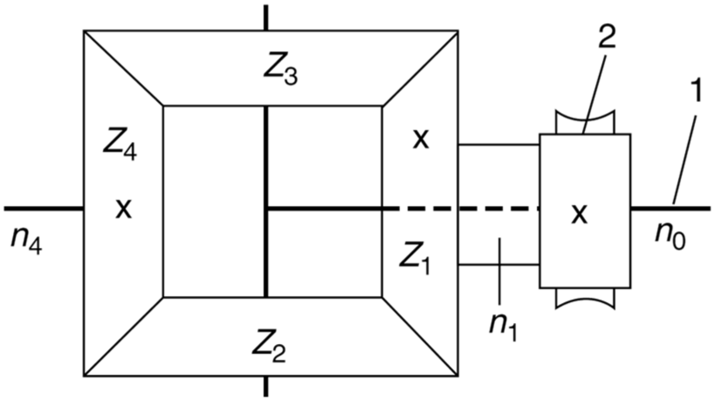
- The advantages of the hydraulic systems are as follows:

1. Has a wide range of speed variation
2. Changes in the magnitude and direction of speed can be easily performed
3. Provides smooth and quiet operation
4. Ensures self-lubrication
5. Has automatic protection against overloads

- The major drawback to a hydraulic system is that the operation of the hydraulic drive becomes unstable at low speeds.
- Additionally, the oil viscosity varies with temperature and may cause fluctuations in feed and speed rates.

MACHINE TOOL DRIVES:

PLANETARY TRANSMISSION



Planetary transmission.

MACHINE TOOL DRIVES:

PLANETARY TRANSMISSION

- Figure 2.46 shows a planetary transmission with bevel gears that is widely used in machine tools.
- Accordingly, any two members may be the driving members, while the third one is the driven member.
- The differential contains central gears Z_1 and Z_4, and satellites Z_2 and Z_3 (an additional wheel) rotated by worm gear 2.

MACHINE TOOL DRIVES:

PLANETARY TRANSMISSION

- The differential can operate as follows (Chernov, 1984):
- 1. Z_4 is a driving member, the carrier is a driven member, and worm gear 2 is stationary.
- 2. The carrier is a driving member, gear Z_4 is a driven member, and worm gear 2 is stationary.
- 3. Gear wheel Z_1 is a driving member (rotated by worm gear 2), gear wheel Z_4 is a driven member, and the carrier is fixed.
- 4. The carrier is a driving member, so is gear Z_1, and gear wheel Z_4 is a driven member.
- 5. Gear wheels Z_1 and Z_4 are driving members and the carrier is a driven member.

MACHINE TOOL DRIVES:

PLANETARY TRANSMISSION

- The principal relationship between axes speed is described by Willis formula, with $Z_2 = Z_3$ and $Z_1 = Z_4$, as follows:

$$i = \frac{n_4 - n_0}{n_1 - n_0} = \frac{Z_2}{Z_4}\frac{Z_1}{Z_3} = -1$$

where

i = conversion ratio

n_0 = speed of carrier rotation

n_1, n_2 = rotational speeds of Z_1 and Z_4, respectively.

- The minus sign in the previous equation indicates that gear wheels Z_1 and Z_4 rotate in opposite direction when the carrier is stationary.

MACHINE TOOL MOTORS

- Most of machine tool drives operate on standard three-phase 50 Hz, 400/440 V ac supply.
- The selection of motors for machine tools depends on the following:

1. Motor power
2. The power supply used (ac/dc)
3. Electrical characteristics of the motor
4. Mechanical features that include mounting, transmission of drive, noise level, and the type of cooling
5. Overload capacity

MACHINE TOOL MOTORS

- Squirrel-cage induction motors are the most popular due to their simplicity, robustness, availability with a wide range of operating characteristics, and low cost.
- Alternating current (ac) motors can provide infinitely variable speed over a wide range; however, their cost is high.
- Direct current (dc) shunt motors with field and armature control are commonly used for the main drives.
- For traverse drives, dc series or compound wound motors are preferred.
- Table 2.8 shows the different machine tool motors recommended for machine tools (Nagpal, 1996).

TABLE 2.8
Machine Tool Motors

Machine Tool	Types of Motor
Lathe	
Main drive and traverse drive	Multispeed squirrel cage
	Adjustable-speed dc
Traverse drive	dc series
	High-slip squirrel cage
Shapers and slotters	Constant-speed squirrel cage
Planers	Multispeed squirrel cage
	dc adjustable voltage
Drilling machines	Constant-speed squirrel cage
	dc shunt motor
Milling machines	Squirrel cage
	dc shunt motor
Power saws	Constant-speed squirrel cage
Grinding machines	
Wheel	Constant-speed squirrel cage
	Adjustable-speed dc
Traverse	Constant-speed squirrel cage

Source: Nagpal, G.R., in *Machine Tool Engineering*, Khanna Publishers, Delhi, India, 1999.

REVERSING MECHANISMS

- Movements of machine tool elements can be reversed by mechanical, electrical, and hydraulic devices.
- Among these are the mechanisms with spur gears and bevel gears.
- Figure 2.47 shows the reversing mechanisms with sliding spur gears (a) and those with fixed gears and clutches (b).
- Figure 2.47 also shows the reversing mechanism with bevel gears and a double-claw clutch (c).
- Hydraulic reversal of motion is effected by redirection of the oil delivered to an operative cylinder using a directional control valve, and electrical reversal is achieved by changing the direction of the drive motor rotation.

REVERSING MECHANISMS

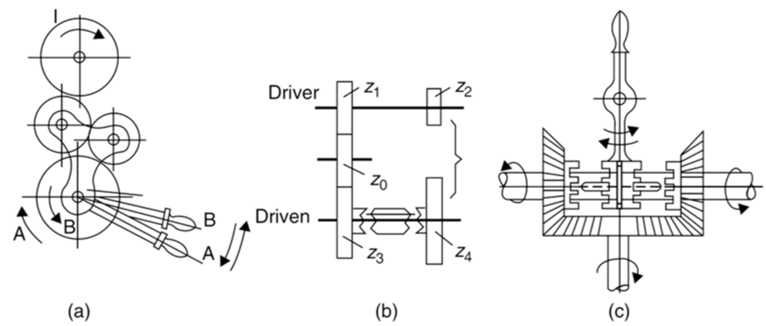


FIGURE 2.47 Reversing mechanisms: (a) tumbler yoke gear, (b) spur gear with clutch, and (c) bevel gear with clutch.

COUPLINGS AND BRAKES

- Shaft couplings are used to fasten together the ends of two coaxial shafts. Permanent couplings cannot be disengaged while clutches engage and disengage shafts in operation.
- Safety clutches avoid the breakdown of the engaging mechanisms due to sharp increase in load, while overrunning clutches transmit the motion in only one direction.
- Figure 2.48 shows permanent couplings.
- Figure 2.49 shows a typical claw clutch (a) and a toothed clutch (b). These two clutches cannot be engaged when the difference
- between the speeds of shafts is high.
- However, a friction clutch (c) can be engaged regardless of the speeds of its two members.
- Additionally, they can slip in case of overloading. Other types of clutches include friction multidisk, contactless magnetic, or hydraulic clutch (Chernov, 1984).

COUPLINGS AND BRAKES

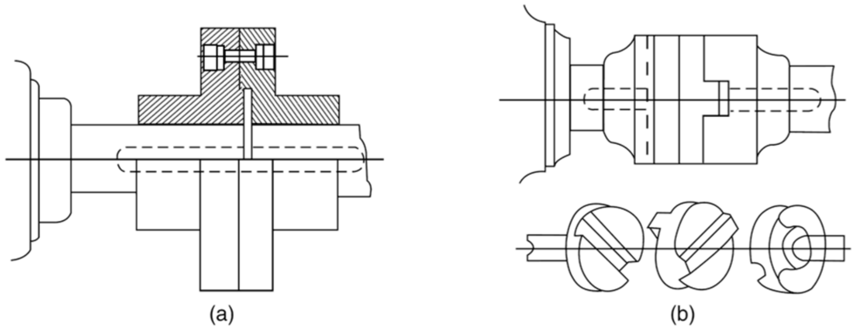


FIGURE 2.48 (a) Flanged coupling and (b) Oldham coupling.

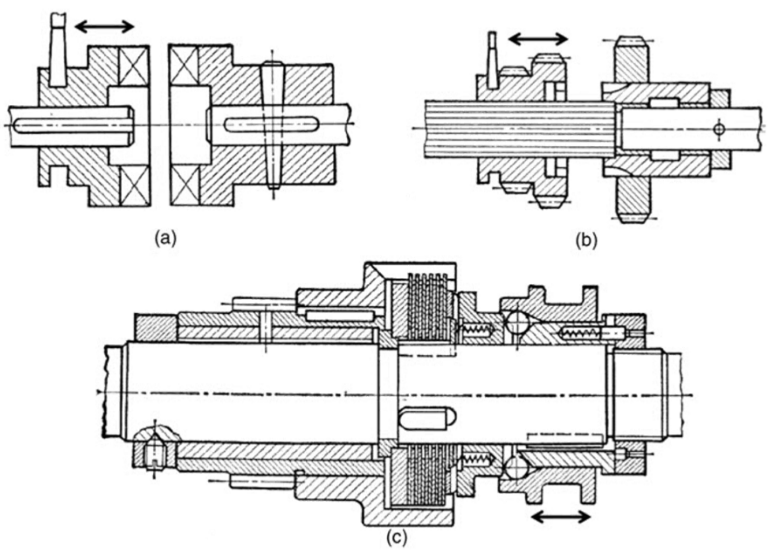


FIGURE 2.49 (a) Claw clutch, (b) toothed clutch, and (c) friction clutch. (From Chernov, N., *Machine Tools*, Mir Publishers, Moscow, 1975. With permission.)

COUPLINGS AND BRAKES

- Brakes are used in machine tools to quickly slow or completely stop their moving parts.
- This step can be performed using mechanical, electrical, or hydraulic (or a combination of these) devices.
- Figure 2.50 shows the shoe brake in which shoes (1 and 6) are connected by a rod (3), whose length is controlled by a nut (2) that controls the clearance between the shoes and the pulley (7).
- Braking is achieved by pressing the shoe against the pulley by an arm (4) driven by the brake actuator (5).
- Band brakes operate frequently by electromagnetic or solenoid actuators.

COUPLINGS AND BRAKES

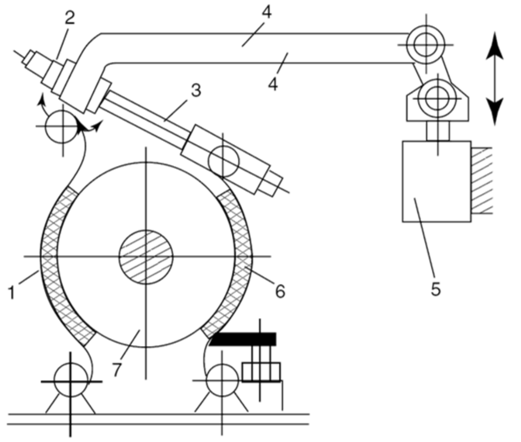


FIGURE 2.50 Shoe brake. (From Chernov, N., *Machine Tools*, Mir Publishers, Moscow, 1975. With permission.)

COUPLINGS AND BRAKES

- In a multiple-disk friction brake, shown in Figure 2.51, when the shaft sleeve (3) is moved to the left, it engages with its lever (2), which, in turn, compresses the clutch disks, thereby engaging the clutch.
- For braking, the sliding sleeve (3) is moved to the right, disengaging the clutch (1) and engaging the friction brake (4).

COUPLINGS AND BRAKES

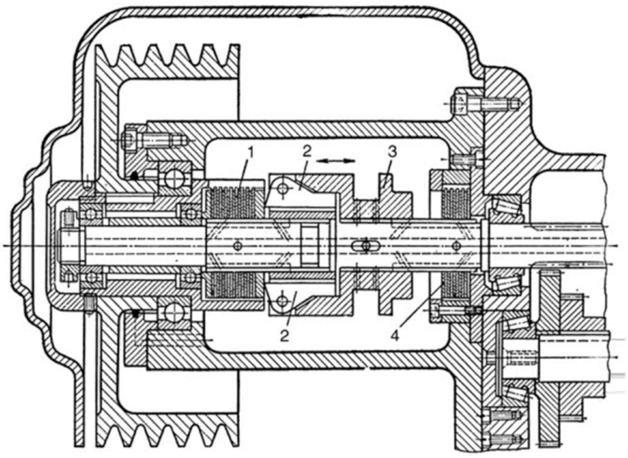


FIGURE 2.51 Friction brake. (From Chernov, N., *Machine Tools*, Mir Publishers, Moscow, 1975. With permission.)

RECIPROCATING MECHANISMS: QUICK-RETURN MECHANISM

- Ruled flat surfaces are machined on the shaping or planing machines by the combined reciprocating motion and the side feed of the tool and WP.
- Figure 2.52 shows the quick-return mechanism of the shaper machine.
- Accordingly, the length of the stroke is controlled by the radial position of the crank pin and sliders A and B.
- The time taken for the crank pin to move through the angle corresponding to the cutting stroke α is less than that of the noncutting stroke β (the usual ratio is 2:1).
- Velocity curves for the cutting and reverse strokes are shown in Figure 2.52. The maximum speed occurs when the link is vertical.

RECIPROCATING MECHANISMS: QUICK-RETURN MECHANISM

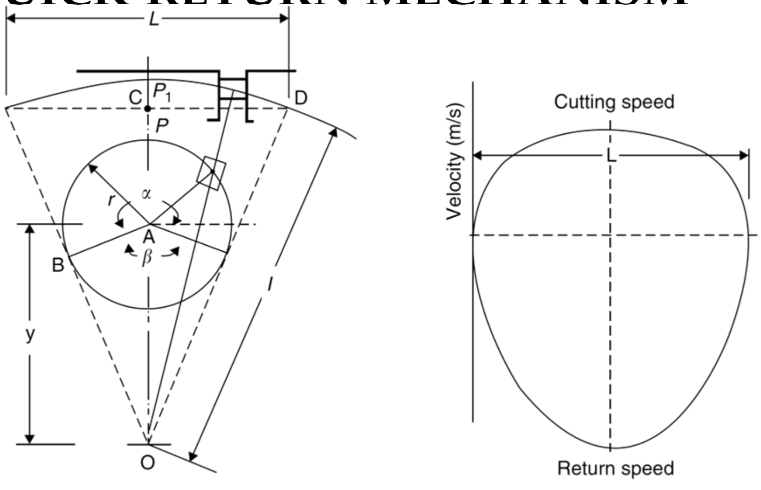


FIGURE 2.52 The quick-return mechanism.

RECIPROCATING MECHANISMS: QUICK-RETURN MECHANISM

- The speed of the link at point P for a given stroke length L will be that at the corresponding crank radius r, hence, the cutting speed v_c at point P_1 is

$$v_c = 2\pi rn \frac{l}{y + r} \text{ m/min}$$

where

n = number of strokes per minute
l = length of crank arm (constant)

RECIPROCATING MECHANISMS: QUICK-RETURN MECHANISM

- Similarly, the maximum reverse speed v_r is given by the following equation:

$$v_r = 2\pi rn \frac{l}{y - r} \text{ m/min}$$

- In terms of the stroke length for maximum radius using similar triangles OBA and OCD

$$\frac{OD}{OA} = \frac{DC}{AB}$$

$$\frac{l}{y} = \frac{L}{2r}$$

RECIPROCATING MECHANISMS: QUICK-RETURN MECHANISM

- Hence

$$v_c = \pi n \left[\frac{lL}{l + L/2} \right]$$

- And

$$v_r = \pi n \left[\frac{lL}{l - L/2} \right]$$

- therefore, the speed ratio, Q

$$Q = \frac{V_r}{V_c} = \frac{2l + L}{2l - L}$$

RECIPROCATING MECHANISMS: QUICK-RETURN MECHANISM

- **Example**

In the slotted arm quick-return mechanism of the shaping machine, the maximum quick-return ratio is 3/2 and the stroke length is 400 mm. Calculate the length of the slotted arm. Calculate the maximum quick-return ratio if the stroke length is 180 mm.

RECIPROCATING MECHANISMS: QUICK-RETURN MECHANISM

- **Solution**
- The quick-return ratio Q

$$Q = \frac{V_r}{V_c} = \frac{2l + L}{2l - L}$$

$$Q = \frac{3}{2} = \frac{2l + 400}{2l - 400}$$

$$l = 1200 \text{ mm}$$

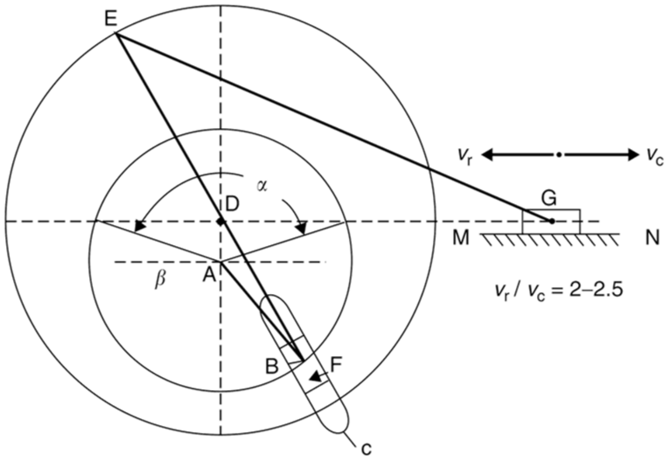
- The quick-return ratio Q, for L = 180 mm

$$Q = \frac{2 \times 1200 + 180}{2 \times 1200 - 180} = 1.11$$

RECIPROCATING MECHANISMS: WHITWORTH MECHANISM

- This arrangement is shown in Figure 2.53; when AB rotates, it drives CE about D by means of the slider F so that G moves horizontally along MN. AB moves through an angle (360° − a) while CE moves through 180°, which is less than 360° − a.
- Also, the crank moves through a while CE moves through 180°, which is greater than a.
- Hence, with a uniformly rotating crank, the link moves through one-half of its revolution more quickly than the other. The angle a is used for the return stroke.

RECIPROCATING MECHANISMS: WHITWORTH MECHANISM



Whitworth quick-return mechanism.

RECIPROCATING MECHANISMS: WHITWORTH MECHANISM

- Hence

$$\frac{\text{Time for cutting stroke}}{\text{Time for return stroke}} = \frac{360 - \alpha}{\alpha}$$

- The stroke can be changed by altering the radius DE, with the angle a being unchanged.
- Provided that the fixed center D lies on the line of movement of G, the ratio of the cutting speed to the return speed lies between 1:2 and 1:2.5.

RECIPROCATING MECHANISMS:

HYDRAULIC RECIPROCATING MECHANISM

- As shown in Figure 2.54, the electrically driven pump supplies the fluid under pressure to the operating cylinder through the solenoid operated valve.
- The piston is connected to the machine table.
- At the end of the forward stroke, the direction control valve reverses the direction of the flow through limit switches set at the stroke limits and the table moves backward.

RECIPROCATING MECHANISMS:

HYDRAULIC RECIPROCATING MECHANISM

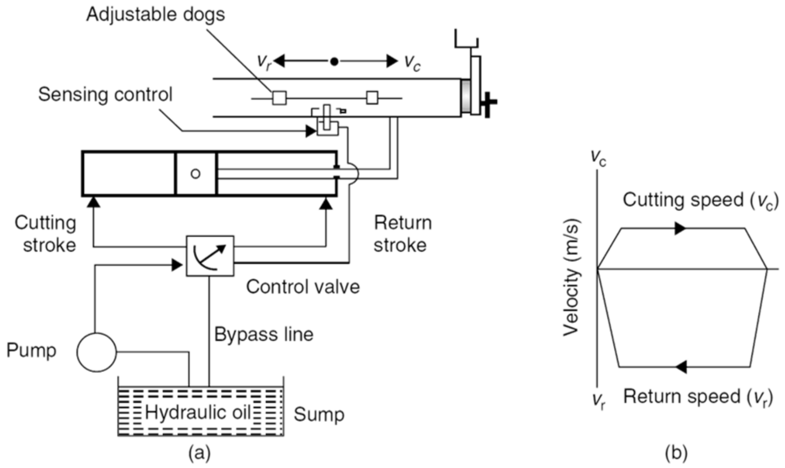


FIGURE 2.54 Reciprocating mechanism (a) and velocity diagram (b) of hydraulic shaper.

MATERIAL SELECTION AND HEAT TREATMENT OF MACHINE TOOL COMPONENTS

- The operating characteristics of a machine tool component depend on the proper choice of the material of each component.
- The most extensively used materials in machine tool components include CI and steels.

MATERIAL SELECTION AND HEAT TREATMENT OF MACHINE TOOL COMPONENTS: CAST IRON

- In the majority of cases, machine tool beds and frames are made of gray CI (see Table 2.9) because of its good damping characteristics.
- If the guideways are cast as an integral part of the bed, frame, column, and so on, the high wear resistance grade CI (GG22 or A48-30B) with pearlitic matrix is recommended for medium-size machine tool beds and frames for a wall thickness of 10–30 mm and the grade GG26 or A48-40B for a wall thickness of 20–60 mm.
- High-strength, wear-resistant special gray CI of the grade (GG30 or A48-50B) with a pearlitic structure can be used for heavy machine tool beds with a wall thickness of more than 20 mm.

MATERIAL SELECTION AND HEAT TREATMENT OF MACHINE TOOL COMPONENTS: CAST IRON

TABLE 2.9
Grades of Gray CI According to DIN 1691, American Iron and Steel Institute (AISI), Society of Automotive Engineers/American Society for Testing and Materials (SAE/ASTM)

DIN 1691	AISI, SAE/ASTM	C (%)	Brinell Hardness Number (BHN) (kg/mm^2)	Applications	Approximate Composition (%)
GG 12	A48-20B	3.5	160	No acceptance test for parts of no special requirements	C = 3.2–3.6, Si = 1.7–3, Mn = 0.5, P = 0.5, S = 0.12
GG 14	A48-26B	3.4	180		
GG 18	A48-30B	3.3	200		
GG 22	A48-30B	3.3	210	Machine parts and frames to withstand high stresses	
GG 26	A48-40B	3.2	230		
GG 30	A48-50B	2.8	240	Machine parts and frames of special quality	C = 2.8–3.0, Si = 1.5–1.7, Mn = 0.8–1.8, P = 0.3, S = 0.12

MATERIAL SELECTION AND HEAT TREATMENT OF MACHINE TOOL COMPONENTS: CAST IRON

- Due to the drawbacks associated with the manufacture of beds and frames by casting, beds and frames are made by welding rolled steel sheets.
- The elastic limit and the mechanical properties of such steel are higher than those of CI.
- Therefore, much less material (50–75%) is required for welded steel structures or beds than CI ones, to be subjected to the same forces and torques, if the rigidity and stiffness of the two structures are made equal.
- CI beds are more often used in large-lot production, while welded steel beds and frames are preferable in job or small-lot production.

MATERIAL SELECTION AND HEAT TREATMENT

OF MACHINE TOOL COMPONENTS: STEELS

- The majority of machine tool components, such as spindles, guides, shafts, springs, keys, forks, and levers, are generally made of steels.
- Since the Young's modulus of various types of steels cannot vary by more than ±3%, the use of the alloy steels for machine tool components does not provide any advantages unless their application is dedicated by other requirements.
- Tables 2.10 and 2.11 show the different types of structural and alloy steels frequently used in machine tools.
- Structural steels are used when no special requirements are needed.
- Case hardening steels of carbon content <0.25%, phosphorous (P) or sulfur (S) should not exceed 0.40% are used when the surface hardness of the component should be very high while the core remains tough.

TABLE 2.10
Structural Steel According to DIN 17100 and AISI, SAE/ASTM

DIN 17100	AISI, SAE/ASTM	C (%)	Mechanical Properties σ_u (kg/mm²)	σ_e (kg/mm²)	δ_5 (%)	Hardening Temperature (°C)	Properties	Applications
St 34	—	0.17	34–42	18	30	920	Case hardenable and weldable	Case hardened parts
St 37	—	0.20	37–45	—	25	920	Low grade, low weldability T° or M°	General machine constructions
St 42	—	0.25	42–50	23	25	880–900	Case hardenable, hard core, machinable, not weldable	Machine elements and shafts withstanding variable loads
St 50	A570Cr50	0.35	50–60	27	22	820–850	Not case hardenable, not weldable, may be hardened, machinable	Machine elements and shafts withstanding heavy loads, not hardened gears
St 52	—	0.17	52–64	35	22	920	High strength, weldable	Welded steel construction in bridges and automotives
St 60	—	0.45	60–70	30	17	800–820	Can be hardened and toughened	Same applications like St 50 but for higher loads, keys, gears, worms
St 70	—	0.60	70–85	35	12	780–800	Can be hardened and toughened	For parts in which wear resistance is recommended

Note: T, Thomas; M, Martin.

TABLE 2.11
Case Hardened Steels According to DIN 17210 and AISI, SAE/ASTM

DIN 17210	Quenching	AISI, SAE/ ASTM	Composition (%) C	Mn	Cr	Ni	Mechanical Properties σ_u (kg/mm)	σ_e (kg/mm²)	δ_5 (%)	Applications
C 10	Water	1010	0.06–0.12	0.25–0.5	—	—	50	29	—	Typewriter parts
C 15		1015	0.12–0.18	0.25–0.5	—	—	55	35	—	Levers, bolts, sleeves
CK 10*		1010	0.06–0.12	0.25–0.5	—	—	50	30	20	Levers, bolts, pins of
CK 15*		1015	0.12–0.18	0.25–0.5	—		55–60	35	15	good surface finish
15Cr3		—	0.12–0.18	0.4–0.6	0.5–0.8	—	70–90	49	12	Spindles, cam shafts, piston pins, bolts, measuring tools
16MnCr3	Oil	5115	0.14–0.19	1–1.3	0.8–1.1	—	85–110	60	20–10	Pinions, automotive shafts, machine shafts
15CrNi6		—	0.12–0.17	0.4–0.6	1.4–1.7	1.4–1.7	95–120	70–90	15–6	Highly stressed small gears
20MnCr5		5120	0.17–0.22	1.1–1.4	1.0–1.3	—	110–145	75	12–7	Medium-size gears, automotive shafts, machine shafts
18CrNi8		—	0.15–0.22	0.4–0.6	1.8–2.1	1.8–2.1	120–145	90–110	14–7	Highly stressed gears, shafts, spindles, differential gears
41Cr4	Cy	5140	0.38–0.40	0.5–0.8	0.9–1.2	—	160–190	130–140	12–7	Cyanided gears

Note: CK 10* and CK 15* are carbon steels of quality better than C10 and C15 due to smaller contents of S and P; Cy, cyaniding.

MATERIAL SELECTION AND HEAT TREATMENT OF MACHINE TOOL COMPONENTS: STEELS

- Typical applications of case-hardening steels are in gears, shafts, and spindles.
- Tempered steels, shown in Table 2.12, contain higher carbon content than case-hardened steels.
- They are used when high strength and toughness are required.
- Nonalloy tempered steels are used for machine components that are not heavily loaded.

MATERIAL SELECTION AND HEAT TREATMENT OF MACHINE TOOL COMPONENTS: STEELS

- For components that are heavily loaded, such as gears, spindles, and shafts, the alloy type is recommended.
- Nitriding steels (see Table 2.13) contain aluminum as the main alloying element.
- After nitriding, the components possess an extraordinary surface hardness and therefore are used for machine parts subjected to wear such as spindles, guideways, and gears.
- The main advantage of the nitriding steel is minimum distortion after nitriding.

MATERIAL SELECTION AND HEAT TREATMENT OF MACHINE TOOL COMPONENTS: STEELS

TABLE 2.12
Tempered Steels According to DIN 17100, AISI, SAE/ASTM

		Composition (%)						Mechanical Properties			
DIN 17100	AISI, SAE/ASTM	C	Si	Mn	Cr	Mo	Others	BHN	σ_u (kg/mm^2)	σ_e (kg/mm^2)	δ_5 (%)
C22	1020	0.18–0.25	0.15–0.36	0.3–0.6	—	—	—	155	50–60	30	22
C35	1035	0.32–0.40	0.15–0.36	0.4–0.7	—	—	—	172	60–72	37	18
C45	1045	0.42–0.50	0.15–0.36	0.5–0.8	—	—	—	206	65–80	40	16
C60	1060	0.57–0.65	0.15–0.36	0.5–0.8	—	—	—	243	75–90	40	14
CK22	1020–1023	0.18–0.25	0.15–0.36	0.3–0.6	—	—	—	155	50–60	30	22
CK35	1035	0.32–0.40	0.15–0.36	0.4–0.7	—	—	—	172	60–72	37	18
CK45	1045	0.42–0.50	0.15–0.36	0.5–0.8	—	—	—	206	65–80	49	16
CK60	1055	0.57–0.65	0.15–0.36	0.5–0.8	—	—	—	243	75–90	40	14
40Mn4	1039	0.36–0.44	0.25–0.50	0.8–1.1	—	—	—	217	80–95	55	14
30Mn5	1330	0.27–0.34	0.15–0.35	1.2–1.5	—	—	—	217	88–95	55	14
37MnSi5	—	0.38–0.41	1.1–1.4	1.1–1.4	—	—	—	217	90–105	56	12
42MnV7	—	0.38–0.45	0.15–0.35	1.6–1.9	—	—	0.07–0.12 V	217	100–120	80	11
34Cr4	—	0.30–0.37	0.15–0.55	0.5–0.8	0.9–1.2	—	—	217	90–105	65	12
41Cr4, 42Cr4	5140	0.38–0.44	0.15–0.55	0.5–0.8	0.9–1.2	—	—	217	90–105	65	12
25CrMo4	4130	0.22–0.29	0.15–0.55	0.5–0.8	0.9–1.2		—	217	80–95	55	14
34CrMo4	4135–4137	0.30–0.37	0.15–0.55	0.5–0.8	0.5–0.15	0.15–0.25	—	217	90–105	65	12
42CrMo4	4140–4142	0.38–0.45	0.15–0.55	0.5–0.8	0.9–1.2		—	217	100–120	80	11
50CrMo4	4150	0.46–0.54	0.15–0.55	0.5–0.8	0.9–1.2		—	235	110–130	90	10
30CrMoV9	—	0.26–0.34	0.15–0.55	0.4–0.7	2.3–2.7		0.1–0.2 V	248	125–145	105	9
36CrNiMo4	9840	0.32–0.40	0.15–0.55	0.5–0.8	0.9–1.2		0.9–1.2 Ni	217	100–120	80	11
34CrNiMo6	4340	0.30–0.38	0.15–0.55	0.4–0.7	1.4–1.7		1.4–1.7 Ni	235	110–130	90	10
30CrNiMo8	—	0.26–0.34	0.15–0.55	0.3–0.6	1.8–2.1		1.8–2.1 Ni	248	125–145	105	9
27NiCrV4	—	0.24–0.30	0.15–0.55	1.0–1.3	0.6–0.9	—	0.07–0.12 V	217	80–95	55	14
36Cr6	—	0.32–0.40	0.15–0.55	0.3–0.6	1.4–1.7		—	217	100–105	65	12
42CrV6	—	0.38–0.46	0.15–0.55	0.5–0.8	1.4–1.7		0.07–0.12 V	217	100–120	80	11
50CrV4	6150	0.47–0.56	0.15–0.55	0.8–1.1	0.9–1.12		0.07–0.12 V	235	110–130	90	10

MATERIAL SELECTION AND HEAT TREATMENT OF MACHINE TOOL COMPONENTS: STEELS

TABLE 2.13
Nitriding Steels

Not Specified in DIN	AISI, SAE/ASTM	Composition (%) C	Cr	Al	Mn	Others	Mechanical Properties σ_u (kg/mm²)	σ_e (kg/mm²)	δ_5 (%)	Applications
27CrAl6	—	0.27	1.5	1.1	0.6	—	85–80	45	16	Valve stems
34CrAl6	A355Cl.D	0.34	1.5	1.1	0.6	—	80–100	60	12	Shafts, measuring instruments
32AlCrMo4	—	0.32	1.1	1.1	0.6	0.2 Mo	80–95	60	12	Steam machinery shafts
32AlNi7	—	0.33	0.7	1.7	0.5	1.0 Ni	88–100	60	14	Piston rods, shafts
31CrMoV9	—	0.31	2.3	—	0.6	0.15Mo/0.1Ni	90–115	75	12	Cam- and crankshaft
30CrAlNi7	—	0.30	0.3	0.9	0.5	0.5 Ni	65–80	45	14	Spindles and shafts

TESTING OF MACHINE TOOLS

- After manufacture or repair of any machine tool, a machine tool test (usually called an acceptance test) should be performed according to the approved general specification.
- Such tests are essential because the accuracy and the surface quality of parts produced depend on the performance of the machine tool used.
- Testing machine tools has the following general advantages:

1. Determines the precision class and the accuracy capabilities of the machine tool
2. Prepares plans for preventive maintenance
3. Determines the actual condition and hence the expected life of the machine tool

TESTING OF MACHINE TOOLS

- Machine tool tests are classified into two categories:

1. geometrical alignment tests
2. Performance tests.

- Geometrical tests cover the manufactured accuracy of machine tools.
- These tests are carried out to determine the various relationships between the various machine tool elements when idle and unloaded (static test).
- They include checking parallelism of the spindle and a lathe bed, squareness of the table movement to the milling machine spindle, straightness of guideways, and so on.
- Static tests are inadequate to judge the machine tool performance, because they do not reveal the machine tool rigidity or the accuracy of machining.

TESTING OF MACHINE TOOLS

- The normal procedure for acceptance tests is made through the following steps:

1. Checking the principal horizontal and vertical planes and axes using a spirit level
2. Checking the guiding and bearing surfaces for parallelism, flatness, and straightness, using dial gauge, test mandrel, straight edge, and squares
3. Checking the various movements in different directions using dial gauges, mandrels, straight edges, and squares
4. Testing the spindle concentricity, axial slip, and accuracy of axis
5. Conducting working tests to check whether the accuracy of machined parts are within the specified limits
6. Preparing acceptance charts for the machine tool that specify the type of test and the range of allowable limits of deformation, deflection, error in squareness, flatness eccentricity, parallelism, and amplitude of vibrations

TESTING OF MACHINE TOOLS

- In contrast, dynamic tests are used to check the working accuracy of machine tools through the
- following steps:

1. Performing an idle run test and operation check mechanisms
2. Checking for geometrical accuracy and surface roughness of the machined parts
3. Performing rigidity and vibration tests

- Standards for testing machine tools are covered by Schlesinger (1961).

MAINTENANCE OF MACHINE TOOLS

- Machine tools cannot produce accurate parts throughout their working life if there is excessive wear in their moving parts.
- Machine tool maintenance delays the possible deterioration in machine tools and avoids the machine stoppage time that leads to lower productivity and higher production cost.
- Maintenance is classified under the following schemes.

1. Preventive Maintenance
2. Corrective Maintenance
3. Reconditioning

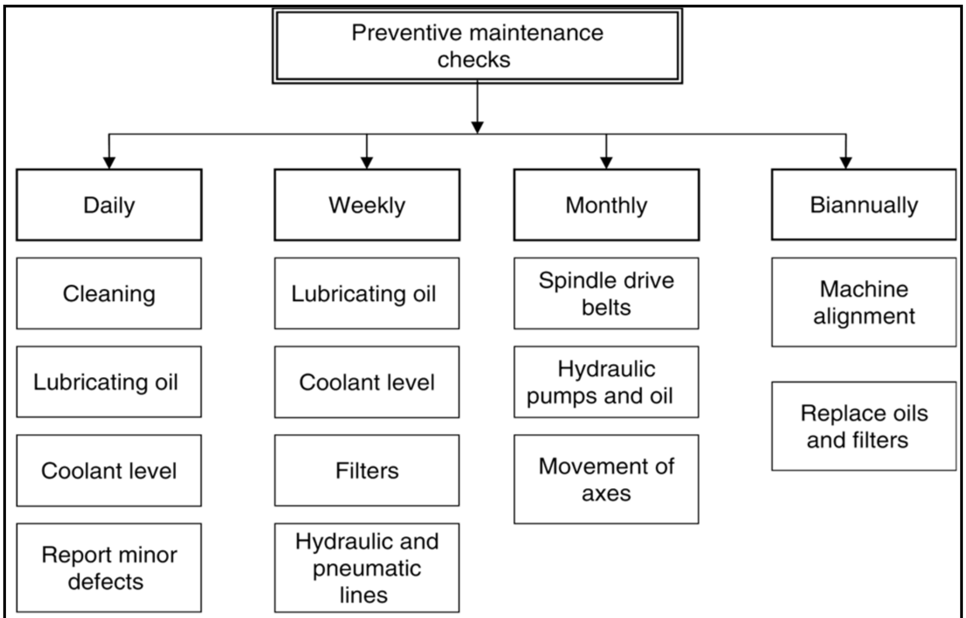
MAINTENANCE OF MACHINE TOOLS:

PREVENTIVE MAINTENANCE

- Preventative maintenance is mainly carried out to reduce wear and prevent disruption of the production program.
- Lubrication of all the moving parts that are subjected to sliding or rolling friction is essential.
- A regular planned preventive maintenance consists of minor and medium repairs as well as major overhaul.
- The features of a well-conceived preventive maintenance scheme include

1. adequate records covering the volume of work,
2. inspection frequency schedule,
3. identification of all items to be included in the maintenance program,
4. well-qualified personnel.

- Preventive maintenance of machine tools ensures reliability, safety, and the availability of the right machine at the right time.



2.55 Preventive maintenance scheme.

MAINTENANCE OF MACHINE TOOLS:

CORRECTIVE MAINTENANCE

- When a machine tool is in use, it should be regularly checked to determine whether wear has reached the level when corrective maintenance should be carried out to avoid machine tool failure.
- A record of all previous repairs shows those elements of the machine tool that need frequent inspection.
- Additionally, such records are used for decisions regarding the need for machine tool reconditioning and replacement.

MAINTENANCE OF MACHINE TOOLS:

RECONDITIONING

- The need for machine tool recondition is determined by the frequency of the corrective maintenance repairs.
- Every machine tool component has a certain life span beyond which it becomes unserviceable despite the best preventive maintenance.
- A major overhaul or reconditioning is required.
- Inspection reports of the machine indicate the components to be replaced, labor time, and the cost estimate.
- As a general rule, it is undesirable to recondition the machine if the cost exceeds 50% of buying new equipment.

REVIEW QUESTIONS

1. State the main requirements of a machine tool.
2. Give examples for open and closed machine tool structures.
3. Explain why closed box elements are best suited for machine tool structures.
4. Sketch the different types of ribbing systems used in machine tool frames.
5. Explain what is meant by light- and heavyweight construction in machine tools.
6. Sketch the different types of machine tool guideways.
7. Show how wear is compensated for in machine tool guideways.
8. Differentiate between cast and welded structures.

REVIEW QUESTIONS

9. Distinguish among the kinematic, structural, and speed diagrams of gearboxes.
10. Show an example of externally pressurized and rolling friction guideways.
11. Show the different schemes of spindle mounting in machine tools.
12. What are the main applications of pick-off gears, feed gearboxes with a sliding gear, and Norton gearboxes?
13. Compare between toroidal and disk-type stepless speed mechanisms.
14. Give examples for speed-reversing mechanisms in machine tools.
15. Derive the relationship between the cutting and the reverse speeds of the quick-return mechanism used in the mechanical shaper.
16. State the main objectives behind machine tool testing.
17. Compare between corrective and preventive maintenance of machine tools.