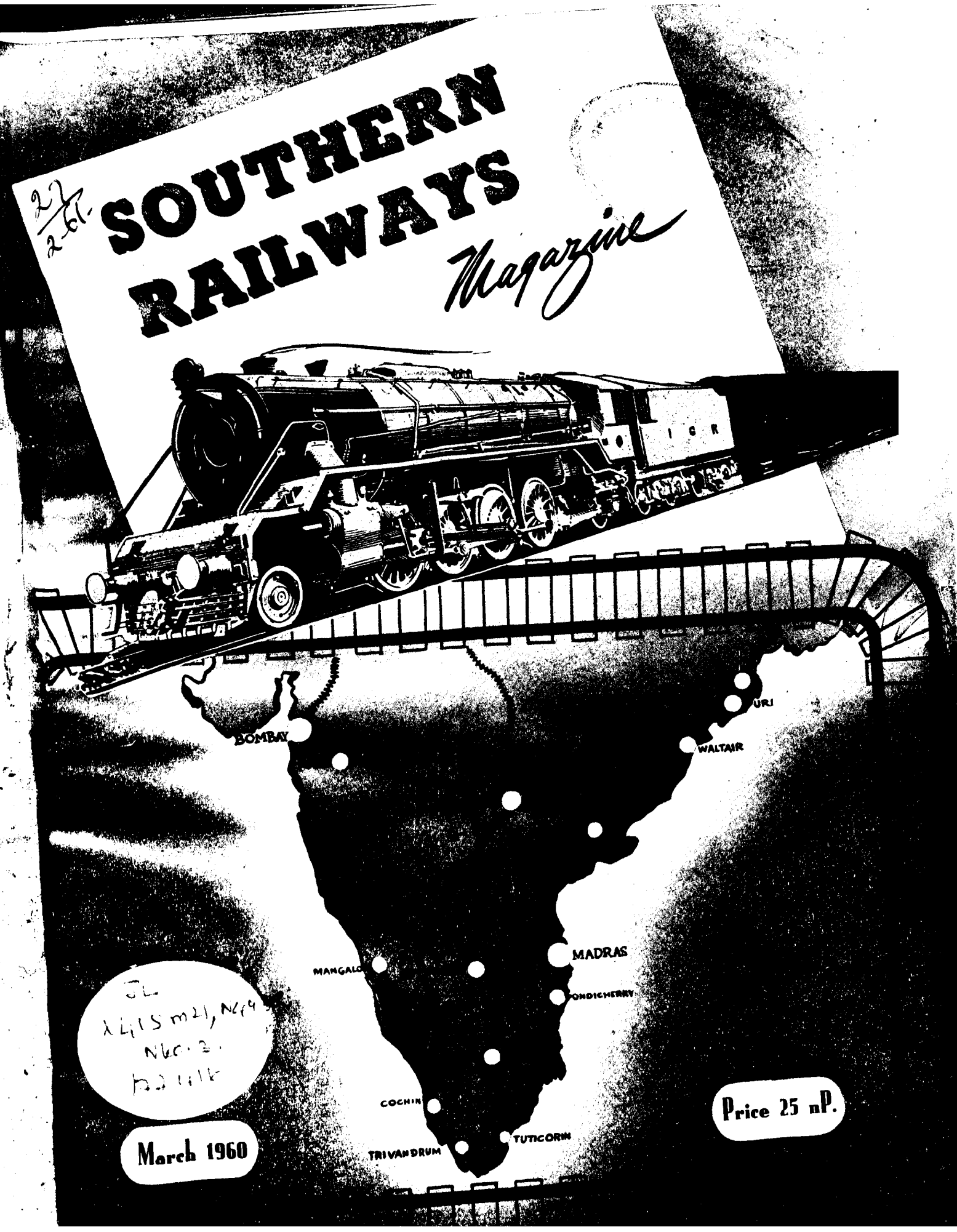




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March 1960

Price 25 nP.

IN YOUR OWN INTERESTS

HOW TO PURCHASE TICKETS

Buy your tickets only at the proper place. The authorised offices are (i) the Booking offices at the railway stations, (ii) the Town or City Booking Offices, (iii) the Out-agencies, (iv) Travel Agent. Never buy tickets from any other source as that may lead you to trouble. Please note that tickets are not transferable.

Buy your tickets in the proper time. You can avoid unnecessary excitement and trouble if you come to the station in good time, that is at least half an hour before the scheduled departure of your train. The Time Tables of the Railway are on sale at Booking Offices and Bookstalls.

Buy your tickets in the proper manner. Queue up at the Booking Window and you can get your ticket easier and quicker than by crowding at the counter.

By handing in the exact fare in good coins or currency you get the ticket easier and quicker, and save for yourself and the Booking Clerk time and trouble.

Check up your ticket and money before leaving the counter and draw the attention of the Booking Clerk to any discrepancy you may notice.

(Inserted in the interests of Travelling Public)

How to Reserve Accommodation ³²/₂₄

Unless you reserve your berth (I Class) or Seats (II and III Class long distance) in advance, you may not be sure of getting accommodation on the train you wish to travel by.

Application should be made to the Station Master of your starting station at least 3 days in advance specifying the date and train by which you intend travelling and the tickets must be bought in advance. The reservation fee leviable is 8 Annas per seat or berth.

Reservation by I and II Class from intermediate stations by Express trains can also be made similarly, but reservation ticket can be issued only after getting an advice from the Reservation Centre that the reservation has been made.

Tickets will be issued only if accommodation is available.

If the reserved seats or berths are not occupied at least 5 minutes before the booked departure of the train the reservation will be cancelled and the seat or berth given away to another.

Reservation fee is not refundable.

III Class seats are also reservable on Express and certain other important trains for long distance passengers from the train-starting stations on payment of a reservation fee of 4 Annas per seat.

Do not occupy a berth or seat reserved for another, as you are liable to be displaced at the last moment.

If you find another person occupying the berth or seat reserved for you and if he will not vacate it on demand, report it to the Guard or Station Master. They will help you.

(Inserted in the interests of Travelling Public)

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2

“FLEXMASTER” PERMANENT WAY MAINTENANCE EQUIPMENT

THE manufacturers of “Flexmaster” equipment produced, several years ago, a full range of special equipment for railway engineers having to look after track maintenance.

The advantage of this equipment is that it employs one motive power unit only, operated by a 2 h. p. petrol engine. The drive from this power unit is taken by means of a flexible shaft drive to a series of track equipments, the most important of which is probably the rail drill. This drill is very robustly designed and is now only supplied in the size referred to in our catalogue as “heavy duty”. It will drill up to 1½” diameter holes in any type of rail. The speed of drilling will vary a little according to the weight of rail. A normal drilling time of about two minutes is required to drill a 1¼” diameter hole. Drills can be provided with suitable adaptation for every size and type of rail and are complete with the necessary adjustments to allow various drillings in the rail ends to be made. The handle is immediately detachable and as the drill stand fits beneath the rail, traffic can pass during drilling operations.

The second attachment is the rail saw. The normal cutting time for a standard 113 lb. rail is usually about six minutes. The rail saw is fitted with a fine adjustment so that when the saw is clamped on, the rail can be cut exactly at the required point. Rail saws are fitted with additional wheel mountings, so that they can be wheeled along the track.

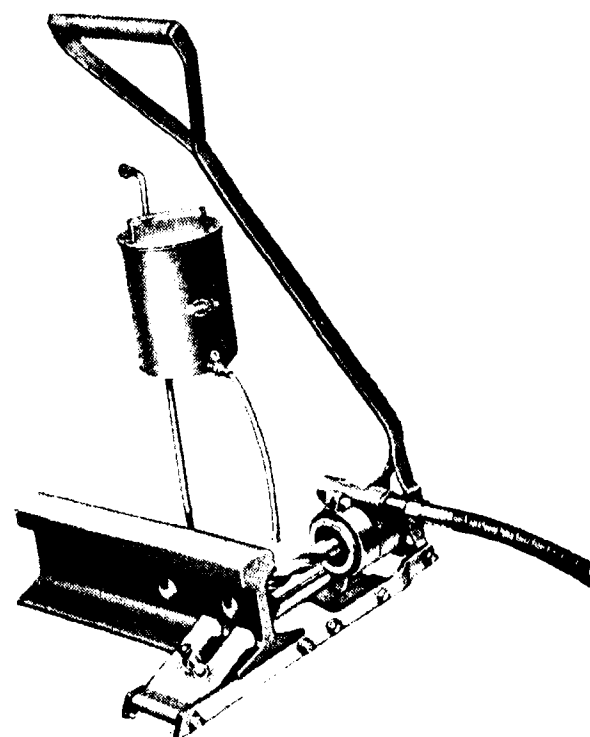
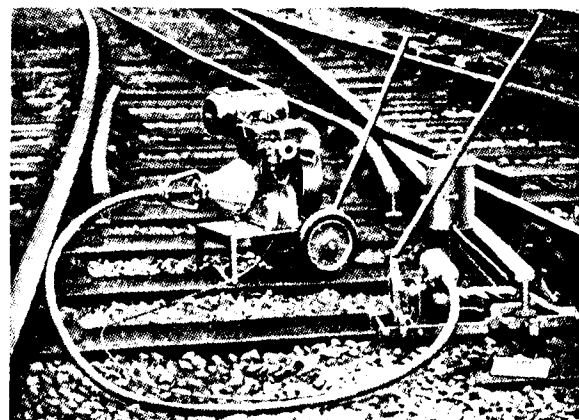
Other attachments are available for surface grinding, welding rail joints, for grinding the sides of rails, points and crossovers, and, where required, “Flexmaster” attachments for bolt running and sleeper boring are also available.

The manufacturers claim that this is the only equipment of its kind supplied with this complete range of interchangeable equipment. Large numbers of these machines have already been supplied and are in constant use by many of the major railway companies, both in Great Britain and in countries abroad.

* * * * *

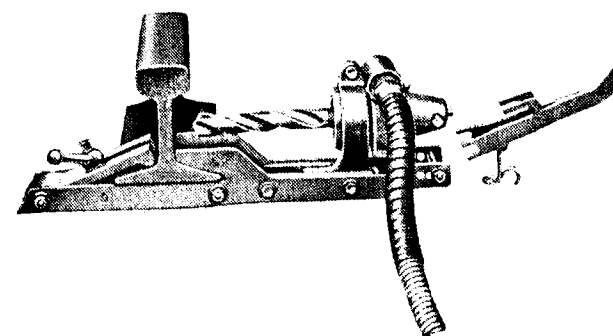
RAIL DRILLING

THE “FLEXMASTER” RAIL DRILLING UNIT is attached underneath the rail. This means that the



The illustrations show the method by which the unit clamps under the rail.
A suds can for coolant supply is provided.
A well balanced and strong handle ensures powerful and steady feed of the drill into the rail.

unit can remain in position while the line is operational. No time is lost in clearing the equipment for the passage of traffic, and the danger of accidents is reduced.



The photograph above illustrates the handle fully withdrawn, allowing ample clearance for the passing of trains. The handle is not permanently fixed to the body of the driller and is, therefore, instantly detachable.

The height of the drill is adjustable in the light duty and standard models by the eccentric mounting of the driller. In the heavy duty model, there is a sliding height adjustment and a gauge bar and block device for the quick and accurate lateral spacing of holes for any given type of rail.

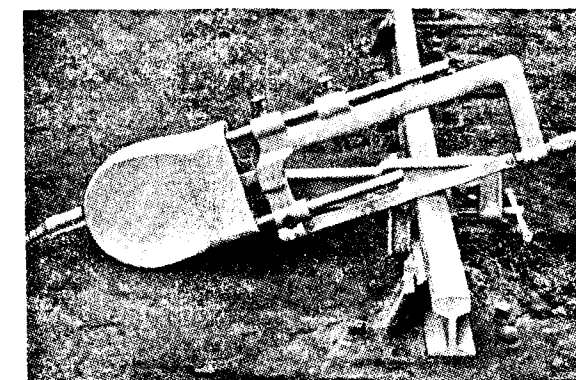
RAIL SAWING

Portable Sawing Attachment

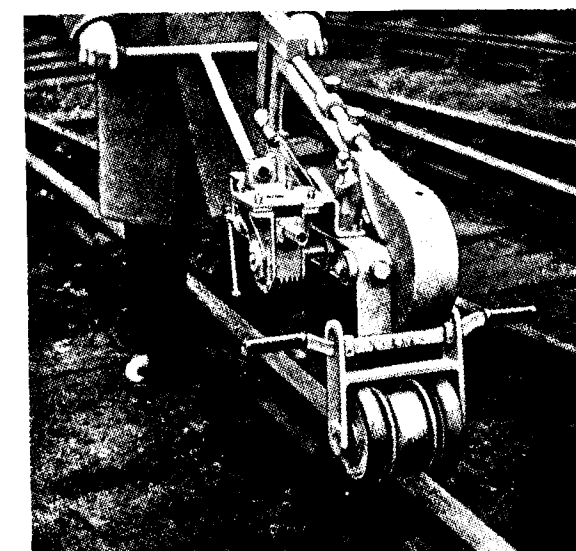
This handy machine is designed to cut up rails or other steelwork accurately, quickly and at a low cost under field conditions. It is not always possible to produce ready cut rails and other steel sections on the site of the work, which means that time and labour are wasted on hand sawing to required lengths. Other methods such as torch cutting and the “nick and break” method have the disadvantage of causing shattered or burnt rail ends or fissures.

Speed of Cutting: This can, of course, be controlled by the adjustment of the throttle of the power unit. An indication of the cutting speed, however, is that the attachment will cut through 113 lb. flat bottomed rail in seven minutes.

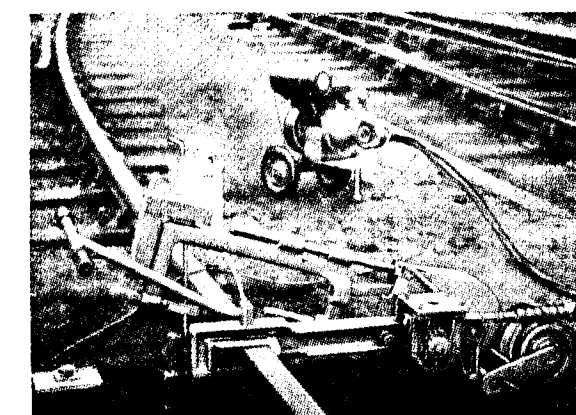
Accuracy: It is possible to remove as little as 3/10 in. from a steel joist or rail, leaving a smooth accurate facing.



Rail Saw



Portable Unit



Portable Unit in working position

Economy: Special high speed saw blades are supplied, which are capable of cutting fifty to sixty 95 lb. B. S. carbon rails before requiring replacement at a cost in fuel of less than six shillings.

172416 2

Fine Adjustment: If accurate placing of the cut is required, the attachment can be supplied with a device for fine lateral adjustment of the saw blade after the unit has been clamped to the rail.

This unit is interchangeable with the remaining attachments which are described in this leaflet, and is powered by a portable petrol unit.

Replacement saw blades can be supplied as required.

Some of Many Uses

1. Cutting steel sections to length when major workshop facilities are not available.

2. Cutting of rails for the correct spacing of joints.

3. Trimming damaged rail ends.

4. Cutting out rails which are cracked or wheel-burnt.

5. Closing of track in rail laying operations.

6. General workshop use where it is an advantage to be able to move the power saw rather than the workpiece.

INSECTICIDAL PAINT

Pitan insecticidal paint is a decorative surface coating which is supplied ready for application by brush, roller, or spray and which kills pests although it is harmless to human beings and animals. The insecticides contained within the paint are stated by the manufacturer to be continually released over a period of at least two years in the form of a fine crystalline film on the surface, which causes flies, cockroaches, and so on to be paralysed and to die within 40-60 min. of making contact.

A wide range of colours is available in gloss finishes for all domestic, industrial, shop, and hospital interior decoration schemes. For steelwork, Pitan metallic lead primer followed by one coat of Pitalux undercoat

is recommended, allowing a minimum drying time of 48 hr. before applying a single coat of Pitan insecticidal paint. For other surfaces, normal preparation before undercoating should include the application of Pitan pink lead primer for new woodwork, Pitan standard emulsion paint for hardboard, and Pitalux alkali-resisting primer for new plaster, brickwork, and previously-painted surfaces. The covering capacity of clear Pitan insecticidal paint is about 80-90 sq. yd. per gal., and coloured, about 70-80 sq. yd. per gal. The price is 64s. per gal.

Further details may be obtained from Allweather Paints Limited, 36, Great Queen Street, London, W.C. 2. (Courtesy: 'RAILWAY GAZETTE')

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I, T.S.S. Rao (alias S. Sundaram) hereby declare that the particulars given above are true to the best of my knowledge and belief.

(Sd.) **T. S. S. Rao**
Signature of Publisher

LUBRICATION BY SOLIDS*

By Dr. J. Gaensheimer

Research Chemist, The Alpha-Molykote Corp., Stamford, Conn.

THE increasing requirements for lubricants which are effective over the wide temperature range from -70 to above 600°C (aircraft and missile industries), which are not affected or decomposed by high-energy radiation (nuclear reactors), which retain their lubricity even in a high vacuum (satellites), and which are chemically stable in corrosive atmospheres (LOX, elementary fluorine, solvents, fuels, chemical industries), launched a search for compounds which would meet all of these requirements.

The traditional liquid lubricants, made of organic materials, oxidize, evaporate, and decompose under these conditions. Therefore, the use of solids as lubricants has received more serious consideration.¹

In addition, complex technical specifications, such as inaccessible bearings, machinery which was to be operable after long storage, and dusty atmospheres had to be satisfied. And, the old problem of lubrication at low speeds and under high loads, where liquid lubricants reach the limit of their applicability and which is present whenever a mechanism is slowed down to a stop or set into motion, may be solved by the use of solids as lubricants.

This is clearly shown by the Stribeck Curve,² which indicates the dependence of the friction coefficient on the viscosity of the oil, the velocity and the applied pressure (Fig. 1).

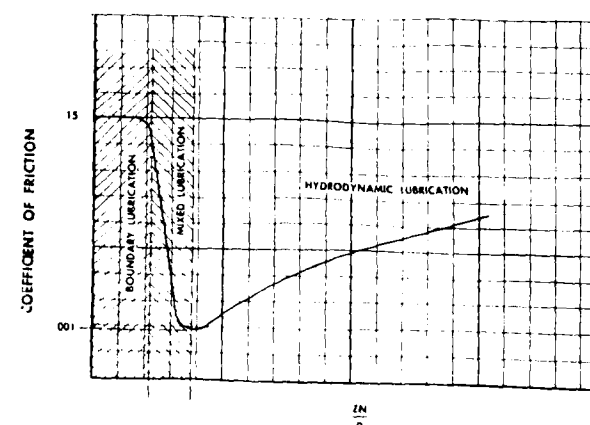


Figure 1. Stribeck Curve. Coefficient of friction vs. ZN/p , where Z = absolute viscosity in centipoise, N = speed in r.p.m., p = average pressure p.s.i.

From this curve it may be seen that the term $\frac{ZN}{p}$ becomes smaller with increasing load and decreasing velocity, moving on the curve from right to left; after reaching the minimum of the curve, the liquid film breaks down, metal-to-metal contact occurs, and the friction coefficient rises very rapidly. It is mandatory to find lubricants which are effective in this range.

MECHANISM OF LUBRICATION BY SOLIDS

Hydrodynamic lubrication and lubrication by solids have one characteristic in common: in either case the mating surfaces are completely separated by a lubricant film, which is sheared during sliding, as shown in Figure 2.

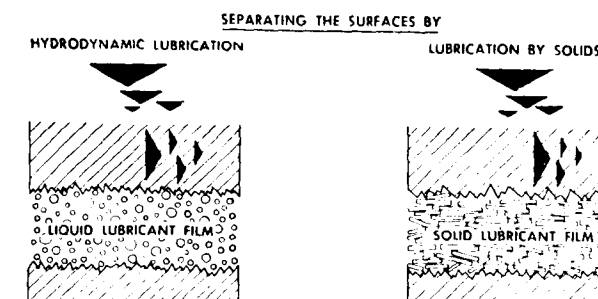


Figure 2. Diagram illustrating the separation of surfaces by thin liquid films or solids.

While the conditions of hydrodynamic lubrication may largely be described mathematically, by the "Laws of Hydrodynamics" as derived by Sommerfeld, Petroff, and Reynolds,³ different laws have to be applied in the case of lubrication by solids.

They will be discussed briefly in the following:

Surface waviness and roughness even on the most accurately machined surfaces are still large enough to prevent contact over the entire bearing area of two mating surfaces. Real contact occurs only at a few high spots of the surfaces and even under low load the pressure on these spots will exceed the yield

*Paper presented at the Seminar on Friction, Lubrication and Wear, Lucerne, Switzerland, Sept. 18, 1959.

pressure of the metal and plastic deformation of the latter will result.

Therefore one has to distinguish between the apparent area of contact and the real area of contact between mating surfaces. The former is given by the geometric dimensions of the surface, while the latter is determined by the load, exerted on the surface, and the yield pressure of the metal. For example, if two flat metal surfaces (steel, yield strength 100 kg./sq. mm.) are superimposed, each having a surface of 21 sq. cm. the apparent area of contact is 21 sq. cm, while the real area of contact is dependent on the applied load and the yield pressure of the metal. This correlation is represented in Fig. 3.⁴

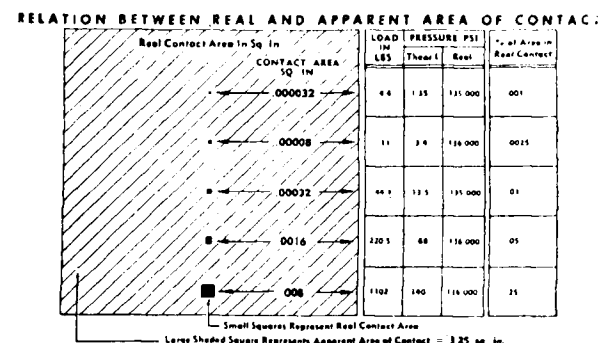


Figure 3. Apparent area of contact in steel flats is represented by large shaded area. Real contact areas at various loads shown to scale by solid black squares. Table gives loads with corresponding values for theoretical and actual bearing pressures.

From this figure it becomes evident that at a load of 2 kg. only 0.001% of the apparent area of contact has actual contact. This real area of contact grows to 0.25% of the apparent area of contact, if the load is increased to 500 kg. In the following equation, this correlation between real area of contact and load is represented:

$$(1) \quad A = \frac{W}{p}$$

Where: A = Real Area of Contact
 W = Load
 p = Flow Pressure of Metal

From this equation becomes apparent: the higher the load and the lower the yield pressure of the metal, the larger is the real area of contact.

If such surfaces are clean and free of contamination a condition for molecular attraction and cold welding exists in the areas of real contact. As sliding motion starts these welded junctions must be broken

and others are reestablished to carry the load only to be sheared again. Thereby, high frictional forces and high wear are observed. The behaviour of the friction force is expressed by the 1st Amonton Law:

$$(2) \quad F = As$$

Where: F = Friction Force
 A = Real Area of Contact
 s = Shear Strength of the Metal Junctions

Substituting $\frac{W}{p}$ from equation 1, for A in equation 2, gives:

$$(3) \quad F = \frac{W}{p} s \quad \text{or} \quad \frac{F}{W} = f = \frac{s}{p} \quad \text{2nd Amonton Law}$$

Where f = Friction Coefficient

If, however, a solid lubricant covers the real areas of contact cold welding cannot occur. There will be plastic deformation of the metal asperities under the solid lubricant and some breaking of these asperities may occur. However, wear damage in this case would be slight compared to damage caused by cold welding. The friction force is then primarily determined by the shear strength of the solid lubricant. This behavior of solid lubricants is shown in Fig. 4.

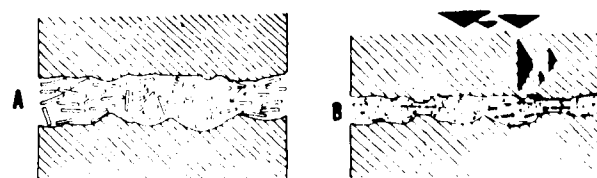


Figure 4. Behavior of a solid lubricant under load. (A) before load is applied (B) after load is applied.

This may also be expressed by the following equation:

$$(4) \quad F = A [a s_m + (1-a) s_s]$$

Where: s_s and s_m signify the shearing strength of the solid lubricant and the metal respectively; a = fraction of A , not separated by the solid lubricant, where metal-to-metal contact has occurred.

By combining equations 1) and 4) the friction coefficient becomes:

$$(5) \quad f = \frac{F}{W} = \frac{A}{Ap} [a s_m + (1-a) s_s]$$

$$f = \frac{a}{p} s_m + \frac{(1-a)}{p} s_s$$

If there is no metal-to-metal contact, when the contacting points are completely separated by the solid lubricant, then $a=0$, and thus $a s_m = 0$, and the friction force F obtained is:

$$(6) \quad F = A s_s = \frac{W}{p} s_s$$

and the friction coefficient f : $f = \frac{F}{W} = \frac{s_s}{p}$

this means: the friction force is now determined by the shearing strength of the solid lubricant and the real area of contact which, in turn, is dependent upon the flow pressure of the base—the flow pressure of the metal—and the load.

Solid lubricants are to be of such nature that the friction force F , or the friction coefficient f in the equations above, become as low as possible.

Numerous tests were run to obtain practical data relative to the behavior of solid lubricants. The comparative tests between liquid and solid lubricants, run on the LFW-2 Testing Machine, appear to be of particular interest and are described in the following.⁵

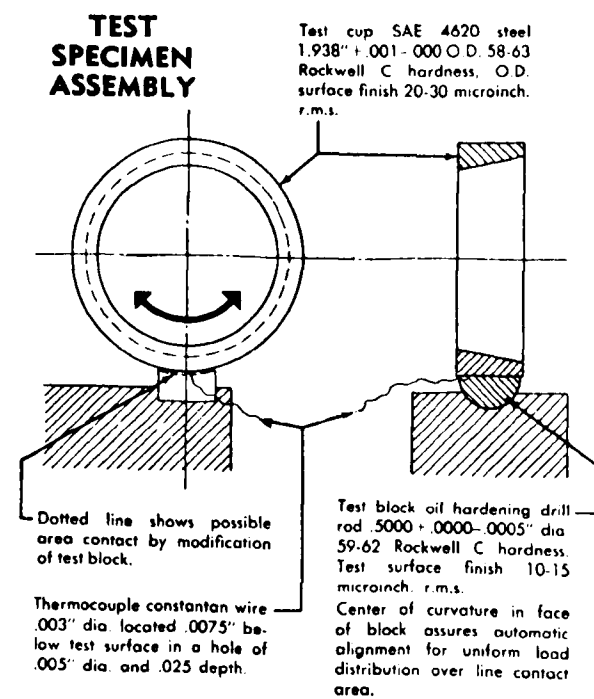
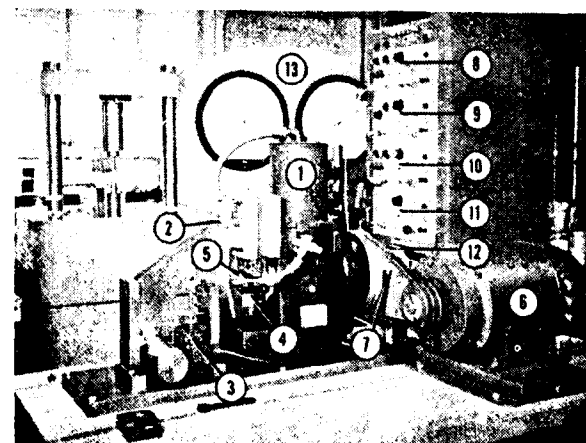


Figure 5.

- 1 Oil Reservoir
- 2 Load Pick-Up (Hydraulic Pressure Transducer)
- 3 Friction Force Pick-Up (2-Directional Load Transducer)
- 4 Test Block
- 5 Test Ring
- 6 Variable Speed Motor
- 7 Generator (Speed Pick-Up)



- 8 For Load Carrier Pre-Amplifier
- 9 For Temperature Low Level Pre-Amplifier
- 10 For Friction Force Carrier Pre-Amplifier
- 11 For Speed D.C. Coupling Pre-Amplifier
- 12 4-Channel Recorder
- 13 Hydraulic Loading Controls of Universal Testing Machine.

Figure 6. General view of testing machine.

FUNCTIONAL DIAGRAM OF TESTING MACHINE

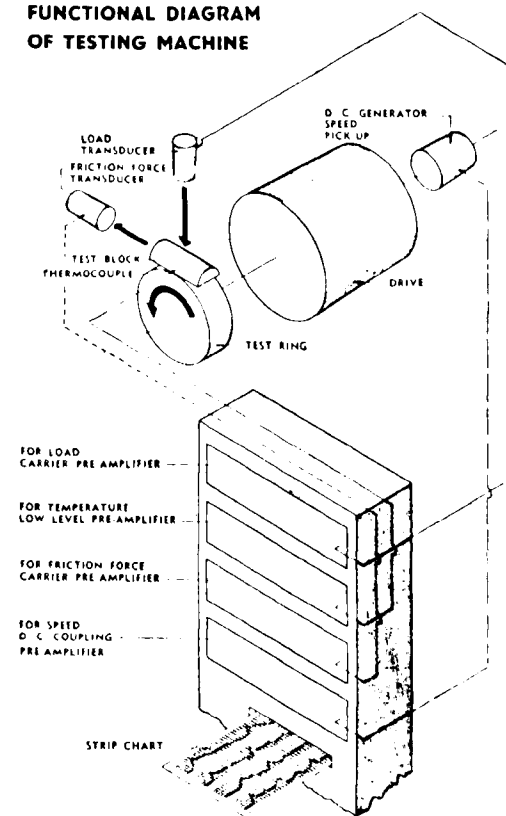


Figure 7.

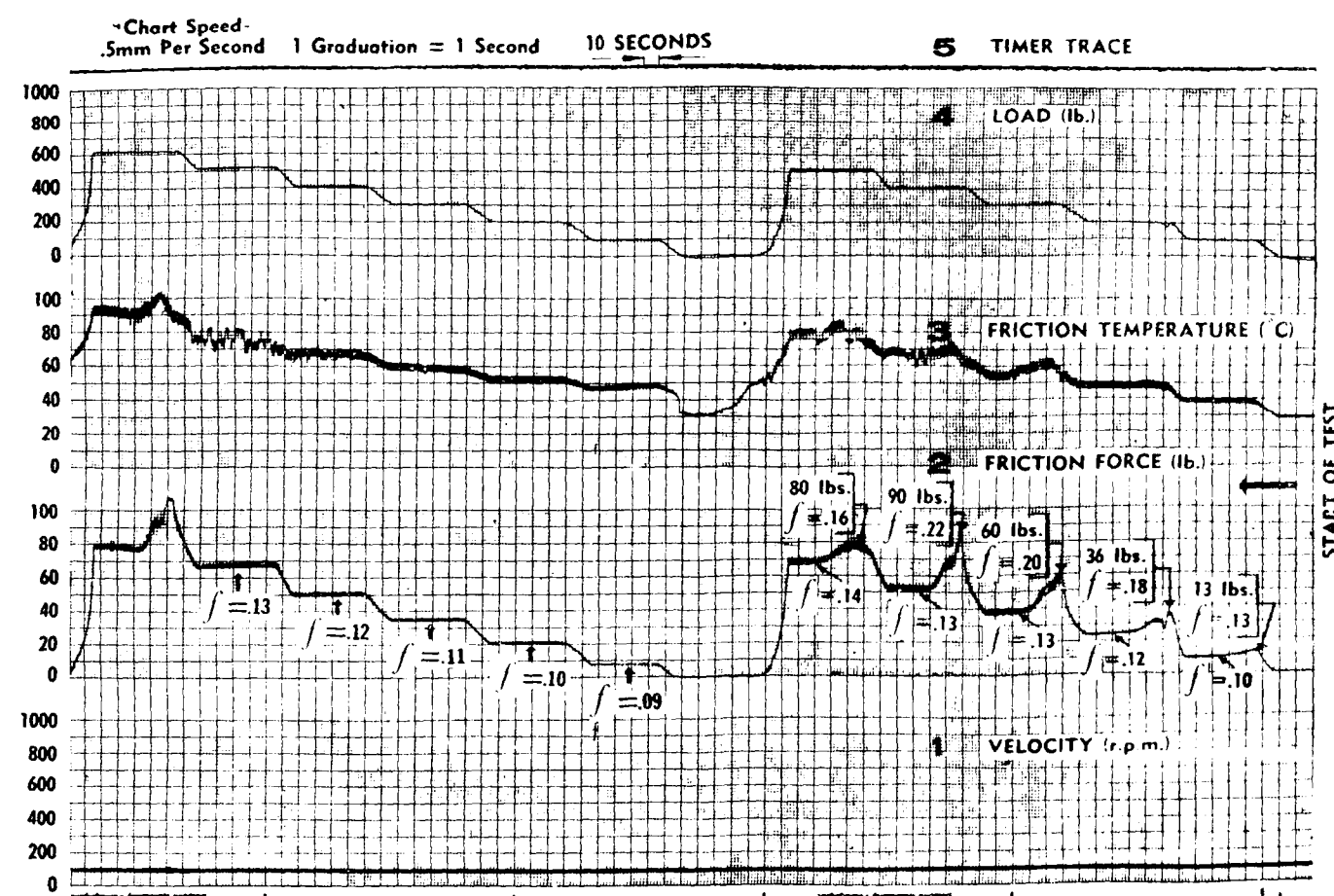


Figure 8. Test showing the wear-in process. Mineral oil SAE 90 containing 5% Zn-P-S-Cl-Additive. Scar width of block after test: .85 mm.

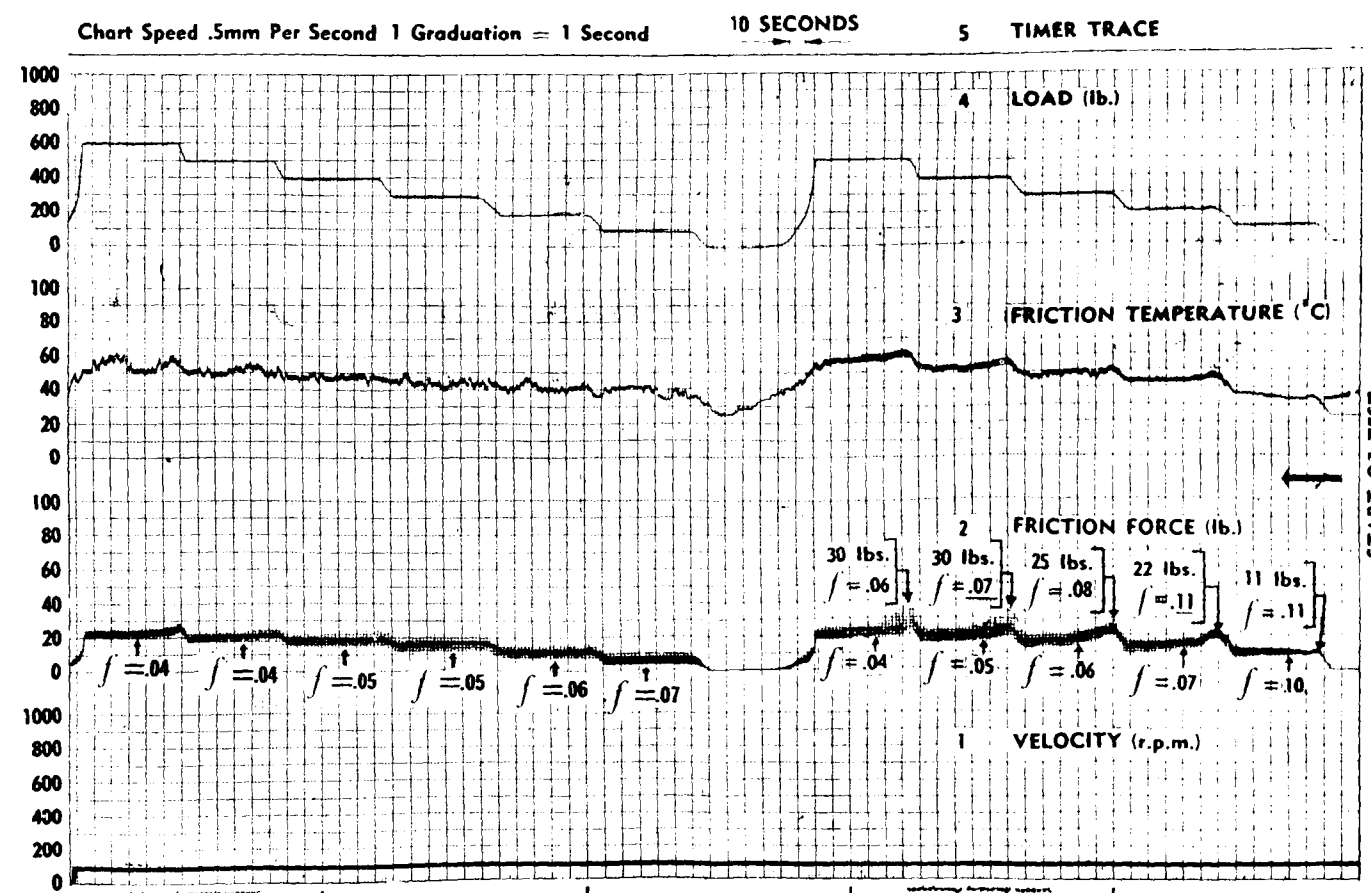


Figure 9. Test showing effectiveness of molybdenum disulfide during the wear-in process. Scar width of block after test: .70 mm. Molybdenum disulfide powder was rubbed on surfaces of test cup and test block. The test was run dry.

For better comprehension, it is necessary to briefly describe the functional characteristics of this lubricant testing machine.

Fig. 5 shows the test specimen assembly. A timken ring slides on a steel block with initial line contact broadening to an area contact as load is applied or wear occurs. This load is infinitely variable from 0 to 1,000 lbs., the speed from 40 to 1,100 revolutions per minute. The average friction temperature is measured by a thermocouple, located 0.0075" below the contact area.

The general view of the testing machine is shown in Fig. 6.

The values for load, friction temperature, friction force, and speed are concurrently recorded by a 4-channel recorder, as schematically shown in Fig. 7.

During the first test run, Fig. 8, an SAE 90 mineral oil containing 5% of a zinc-phosphorus-sulfur-chlorine additive was used. The speed was constant, 100 revolutions per minute. The load was increased by 100 lbs. every 60 sec. From the figure it may be seen that, concurrently with every load increment, there is a substantial increase of the friction force curve and a slight increase of the friction temperature curve.

The peaks indicate that, at this moment, the actual contact surface between both test specimens is being enlarged, until the increased load can be carried. From the high friction values which are occurring, it may be concluded that this occurs partially by shearing of the formed metal-to-metal contacts. As soon as an adequate contact area has formed, the friction force drops to a constant value. The friction coefficient in this constant range fluctuates between 0.09 and 0.14, according to the magnitude of the load. These relatively high values permit the conclusion of high shearing strength of the reaction products between the additive and the metal surface.

When repeating the load cycle, no peaks will occur in the friction force and friction temperature curves, until the maximum load of the first cycle has been exceeded. This is understandable since, during the first load cycle, the real area of contact had already been enlarged. Only after exceeding the maximum load of the first cycle are peaks again observed in the friction force and frictional temperature curves, since the real area of contact must now again be enlarged, to carry the increased load.

The second test, refer to Fig. 9, was run in the same manner as test 1. In contrast to the liquid lubricant, a solid was used as a lubricant, namely molybdenum disulfide. The timken ring and the test block were carefully cleaned in a solvent and molybdenum disulfide powder (average particle size: 10 microns) was rubbed on with a paper napkin.

When comparing Figures 8 and 9, it becomes immediately apparent that friction force peaks, temperature and friction force curves show much lower values in the case of the solid lubricant.

The friction coefficient drops with rising load, from 0.1 at a load of 100 lbs. to 0.04 at a load of 500 lbs. a characteristic property of molybdenum disulfide. This behavior denotes that the surfaces are coated with a molybdenum disulfide film, whereby metal-to-metal contact and wear are reduced. The lower friction force is due to the low shear strength of molybdenum disulfide.

In order to establish if the enlargement of the real area of contact using molybdenum disulfide as a lubricant was sufficient to carry the load for subsequent oil lubrication a third load cycle using the same EP oil used in Test 1 is shown in Fig. 10.

From this figure it can be seen that, in the 3rd cycle, there are no prominent peaks until the maximum load of the 1st and 2nd cycle is exceeded, i. e., when using the solid lubricant, the enlargement of the real area of

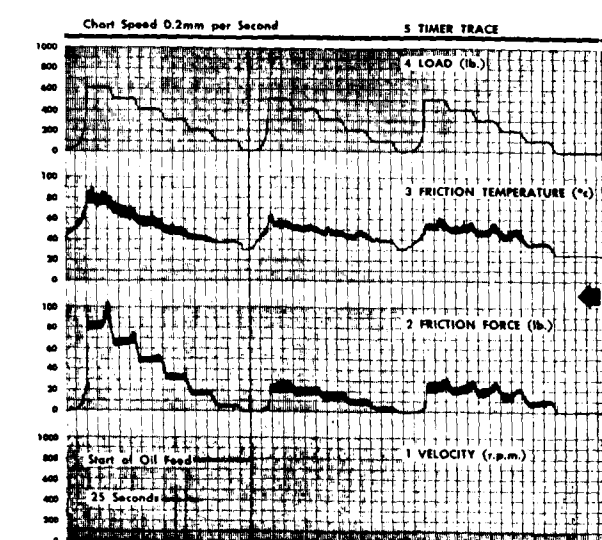


Figure 10. Test showing wear-in effectiveness of molybdenum disulfide for subsequent oil lubrication. Molybdenum disulfide powder was rubbed on surface of test cup and test block. After second loading cycle, the same oil as used in Figure 8 was flooded over specimens. Scar width of block after test: .79 mm.

contact is obtained by the deformation of the metal surface below the solid lubricating film, with little if any shearing or breaking of surface asperities.

Reflections of this kind may also explain the effectiveness of solid lubricants against the formation of pitting. It may be assumed that pitting results from fine hairline cracks which form on surfaces as a result of residual and induced tension and compression stresses.⁶ This is suggested by Fig. 11.

Liquid lubricants, can enter these capillary spaces due to their surface forces and then tend to widen these cracks by continuous compression during sliding until finally a piece of the metal breaks off as is indicated in Fig. 12.

Failures of this type are unlikely with solid lubricants. The crack will be covered by the solid and the progression of the crack is not favored by the lubricant. Fig. 13.



Figure 11. Progressing hairline crack.



Figure 12. Influence of liquids on progressing hairline crack. Due to capillary action and pressure, liquids enter the cracks and tend to widen and break them.

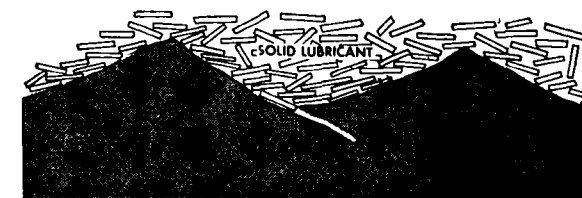


Figure 13. Influence of solids on progressing hairline crack. The solids cover the opening of the crack and at least do not favor the progressing of the crack.

After making several reflections on the mechanism of lubrication by solids, the following questions should be answered. What should a solid lubricant look like; what properties should it have; and which solids are presently used for lubrication purposes?

In order to keep the friction force F in equation 6 as low as possible, the shear strength of the solid lubrication should be as low as possible. The solid

lubricant should adhere well to the surface; it should completely cover the surface, to prevent metal-to-metal contact. It should be elastic and of great strength within the individual layers to prevent that the solid lubricating film is penetrated by the surface asperities.

CLASSIFICATION OF SOLID LUBRICANTS

Solid lubricants may be classified into the following groups, according to their chemical and physical structures:

(1) Inorganic solid lubricants

(a) with layer lattice structure, (b) other inorganic compounds, (c) inorganic conversion coatings, (d) metals.

(2) Metal organic and organic solid lubricants

(a) EP Additives, (b) Waxes, Fats, Soaps, and Fatty Acid Salts, (c) Plastics.

(1) Inorganic Solid Lubricants

(a) Lubricants with Layer Lattice Structure

The two best known and most used representatives of this group, undoubtedly, are graphite and molybdenum disulfide.

Graphite⁷ is extensively used as a lubricant and has been known for a long time. It has been used in technology for at least 100 years. Its lubricity is attributed to its layer lattice structure, as is shown in Fig. 14.

Weak van der Waals' bonds between the hexagonal carbon layers permit easy movability of these layers relative to each other, while strong bonds within the layers guarantee high resistance against penetration by surface asperities. But numerous investigations during the past years have shown that this layer lattice structure theory is a simplified explanation of the problem. For example, Savage has conducted tests in which he used graphite as a lubricant in high vacuum. It became evident that the introduction or removal of water vapors resulted in low friction and wear or high friction and wear, respectively.

Apparently the absorbed liquid and gas molecules play a decisive role in the lubrication by graphite. But by the addition of inorganic materials, such as barium fluoride or lead iodide, a good lubricating effect may

also be obtained in high vacuum. In addition, there are several indications in the literature that the good lubricating properties of compounds having layer lattice crystal structures are due to the shearing of weak-bond crystallites rather than monomolecular layers. But these hypothesis on details of lubrication with graphite are not at all generally recognized and, therefore, we may still accept the more impressive and easily understood theory that the layer lattice structure is the cause of the good lubricating properties.

If graphite is heated in air, it will react with the oxygen in the air and carbon dioxide will form, a gas. This reaction starts noticeably at 450° C (842° F). Since a gas is formed as a reaction product, no abrasive particles will remain after the oxidation. The chemical stability of graphite is very good. Practically, it is not affected by atomic radiation.

Molybdenum Disulfide :*

The history of molybdenum disulfide goes far back into the past, but molybdenum disulfide products have been on the market for only 11 years and are now in use as special lubricants all over the world. The most plausible explanation for its effectiveness as a lubricant again is its layer lattice structure, which is shown in Fig. 15.

The sulfur-molybdenum-sulfur layers slide easily one on another, since they are kept together only by weak van der Waals forces or may even be mutually repellent, because the opposite sulfur layers have identical electrical charges. But within the individual layers, the cohesive forces between the sulfur and molybdenum atoms are very strong and thus resist penetration by surface asperities. Since the sulfur atoms have a strong affinity to metals, i. e., a high tendency to bond to metals, the molybdenum disulfide crystals exhibit excellent adhesiveness on metal surfaces. In contrast to graphite, molybdenum disulfide retains its lubricity even in high vacuum. Its oxidation in air into molybdenum trioxide starts slowly approx. at 300° C (572° F) and rises sharply at 400° C (752° F) depending on particle size and time of exposure. The resulting molybdenum trioxide no longer acts as a lubricant, it is rather slightly abrasive and a weak acid. But even at high temperatures, molybdenum disulfide may retain its lubricity for an extensive period of time, as long as only the surface of the lubricating film oxidizes and a thin, non-oxidized molybdenum disulfide layer is still present, as is schematically shown in Fig. 16.

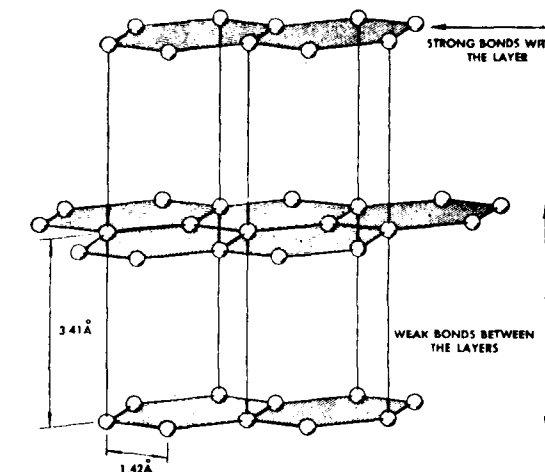


Figure 14. Crystal structure of graphite.

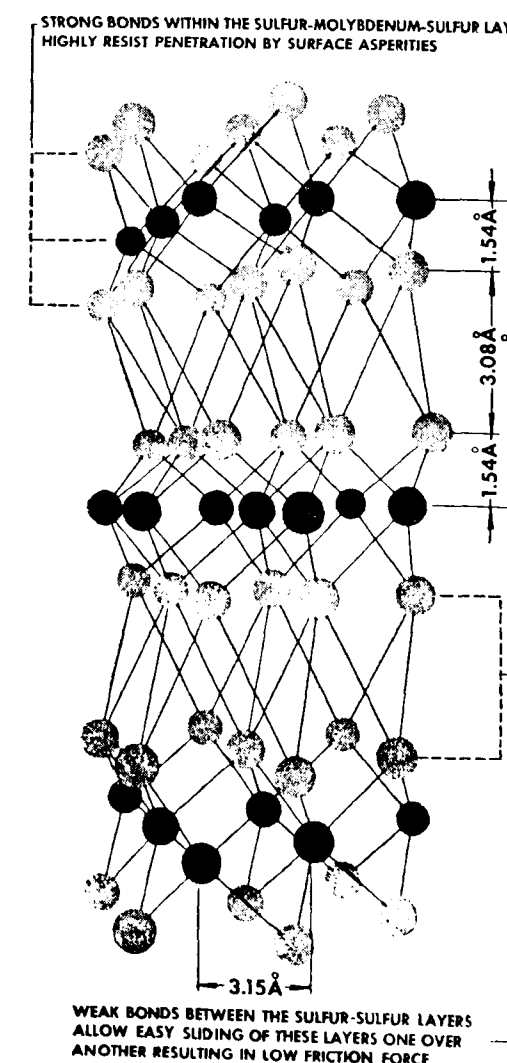


Figure 15. Crystal structure of molybdenum disulfide.

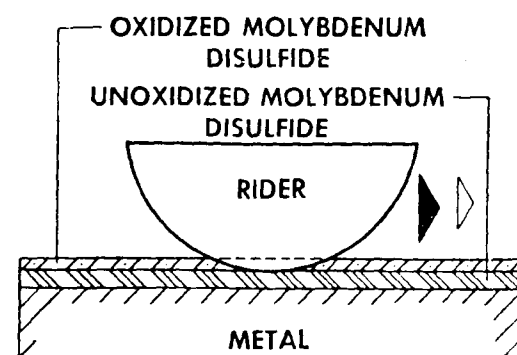


Figure 16. Lubricating properties of a partly oxidized molybdenum disulfide film.*

In this schematic presentation, a partially oxidized molybdenum disulfide film is shown. Between the oxide layer and the metal surface, there is an unaffected molybdenum disulfide film which has a lubricating effect and prevents metal-to-metal contact between the rider and the metal surface of the block. Only after the entire layer has oxidized into molybdenum trioxide does lubrication break down. Similar to graphite, the stability of molybdenum disulfide against chemical attack and atomic radiation is very high.

In order to obtain effective lubrication results with these solid lubricants, especially 2 factors must be taken into consideration:

- (1) The lubricant must adhere to the surface in order to deploy its full lubricity;
- (2) The lubricant should be replaced to the extent to which it is rubbed off or it should be applied of such thickness that a suitable life is guaranteed;

Therefore, graphite and molybdenum disulfide are always used in one of the following forms:

as dry powders; in form of a dispersion (pastes and greases should be included in this category); or as bonded coatings.

Application of Powders:

For many purposes it is adequate to apply the powder by using a rag or a paper napkin tissue by hand to the surface. Tumbling is also an excellent method if the powder is to be applied on numerous small parts. For best results, it is important to carefully clean the surfaces on which the lubricant is to be applied. Finger prints, dust, rust, grease or dirt

spots of any kind prevent good adhesion of the lubricant on the surface. A properly applied film of a solid lubricant effectively reduces friction and wear, as was shown in the LFW-2-tests mentioned above. Molybdenum disulfide appears to exhibit better results in dry applications than graphite, which may be attributed to its excellent adhesiveness on metal surfaces which, as previously mentioned, is affected by the sulfur atoms.

Application in Dispersions:

Both lubricants are largely used in the form of dispersions. With graphite, due to its low specific weight of 2 to 2.3 as compared to the specific weight of 4.7 to 4.8 of molybdenum disulfide,¹⁰ and due to its easily obtainable small particle size, stable suspensions may be prepared without great difficulty. This however, is a real art in the case of molybdenum disulfide. Dispersions are a reservoir of solid lubricant, which may then be carried to the lubrication area by the liquid, as required. Dispersions are primarily used as EP additives for liquid lubricants and metal working fluids. Pastes are mixtures of the solid lubricant in liquids; they contain a high concentration of solid lubricant and are used in cases which do not permit the application of dry solid lubricants, such as inaccessible lubrication areas or where the application of the powder is too complicated. They may easily be applied on surfaces by coating with a brush. The lubricating properties of conventional greases may be fortified by the addition of solid lubricants; they will then resist higher pressures and diminish wear.¹¹

The purpose of these dispersions, pastes, and greases is the formation of a solid lubricating film on the metal surface during operation. This film, for a certain period, permits emergency lubrication* if, for any reason, the liquid lubricant should fail, due to too high loads or due to leakage or, for example, due to bleeding of greases.

Dispersions of solid lubricants are commercially available in all liquid lubricants, such as mineral oils, polyglycols, silicone oils,¹² diester oils, or volatile liquids such as water or low-boiling hydro-carbons, which evaporate during operation, leaving a solid lubricant film on the surface.

The preparation of such dispersions requires care: the dispersion agents must be selected in such manner

*Lubrication by solid lubricants after failure of oil film.

that they keep the lubricant particles in suspension for a long time and do not keep the particles from reaching the metal surfaces and adhering to them.

Application of Bonded Coatings:

When using dry lubricants in the form of bonded coatings,¹³ the solid particles are, together with a binder, dispersed in a suitable volatile solvent so that they may be applied to surfaces by brushing, dipping, or spraying, exactly like a paint or varnish. Naturally, the binder must be carefully selected since it has to attach the solid lubricant to the metal surface; it should not impair the lubricating properties of the solid lubricant; it should be a corrosion inhibitor, stable against high temperatures, elastic, and should not be attacked by liquids to which it may possibly be exposed during operation.

Practically all resins and plastics have been investigated and tested for these purposes. As a direct result, several bonded coatings are now on the market, which are either air-drying or must be baked at elevated temperatures, such as at 150° C for 60 minutes. These bonded coatings are applied at a thickness of 0.0002 to 0.0003"; thus, they provide the surfaces for a long period with a lubricant; often they provide lubrication for the life of the workpiece. The wear life of these bonded coatings depends on several factors, such as humidity, surface roughness, and others, but—to a particularly large extent—on surface pretreatments such as sandblasting or phosphating.

The bonded coatings lead directly to another technique for application of solid lubricants, namely in mixture with plastics, such as nylon, where they provide this abrasion-stable polymer with a low friction coefficient or added to sintered metals, where they transfer their good lubrication properties to the latter.¹⁴

The knowledge that graphite and molybdenum disulfide are excellent lubricants, due to their layer lattice structures, led to an intensive search for other compounds with layer lattice structure to find possibly new more universally applicable solid lubricants. Practically all inorganic layer lattice compounds were investigated and tested on lubricant testing machines, including stannic disulfide, cadmium iodide, lead chloride, mercury chloride, copper chloride, nickel hydroxide, barium hydroxide, calcium hydroxide, silver iodide, silver sulfate, boron nitride, tungsten disulfide, tellurides of molybdenum and tungsten and many others. But none of these compounds showed

lubricating properties comparable to those of graphite or molybdenum disulfide, with the exception of tungsten disulfide which shows lubricating properties similar to those of molybdenum disulfide.¹⁵

(b) Other Inorganic Compounds

Besides inorganic layer lattice compounds, other inorganic materials have also been investigated for their suitability as lubricants, such as boron trioxide, various ceramic materials and, primarily, basic lead carbonate ("white lead") and lead monoxide.¹⁶ The latter is said to be suitable for lubrication, primarily at very high temperatures, namely approx. 700° C (1,292° F). It exhibits the favorable frictional values under high velocities (up to 10,000 ft. per minute) and at high temperatures (up to 700° C).

At room temperature, high friction is observed, mainly due to the formation of the red lead oxide, Pb_3O_4 , from the lead monoxide, which again is reversibly changed into lead monoxide at elevated temperatures. These lubricants have not yet gained great or practical significance.

(c) Inorganic Conversion Coatings.

The best known chemical surface treatment is phosphating.¹⁷ Thereby, a thin, dense, fine crystalline, very adhesive, water insoluble, slow-reacting phosphate layer is deposited on the metal surface. The origin of these layers can be traced back to the search for corrosion-protected surfaces. In the year of 1906, the Englishman Thomas W. Coslett was granted a patent relating to the corrosion protection of iron and steel by treatment with hot, diluted phosphoric acid. This procedure, in the meantime, has been much perfected and, today, mainly zinc, iron, and manganese-phosphate layers, or mixtures of them, are produced on iron and steel surfaces. It has been discovered that especially iron and manganese-phosphate layers reduce the scoring of machine parts, which occurs especially during wear-in of new parts, and that especially zinc-phosphate layers facilitate the forming of steel. In both cases the result is particularly good if, together with the phosphate layer, conventional lubricants, liquid or solid, are used. Phosphate layers have been used for the forming of steel, particularly in drawing wires, rods, tubes and cups. They favor the adhesiveness of lubricant films, due to their fine crystalline surface structure, and prevent their break-down. Scoring of drawn parts is reduced since the phosphate layer effects a good separation of the work from the tool.

Recently, attempts have been made to produce the phosphate layer and the lubricant layer, in one operation on the metal surface, by using long-chain organic phosphorous compounds. The phosphorous group of the compound reacts with the metal and is intended to effect good adhesion, while the organic radical is intended to assume the function of lubrication.¹⁸

The best phosphate layers are produced by the dipping process, though they may be produced by all conventional methods, such as brushing, spraying, and tumbling. Particularly good phosphate coatings are obtained on iron, zinc, and cadmium surfaces, while aluminum and magnesium are less suitable. Therefore, fluorine-containing chromium baths are used for these light metals, which produce very adhesive oxide and oxide-chromate layers on these metals. These oxide or oxide-chromate layers are always essentially thinner than the phosphate layers; their thickness is always less than 1 micron (0.1—1 micron) while the phosphate layers exhibit a thickness of 2 to 5 micron.

Besides these phosphate layers, oxide, sulfid, chloride, and oxalate layers have been described in literature and are applied in technology; however, these are by far not as widespread as the discussed phosphate layers.

In conjunction with these chemical surface layers, it should be mentioned that practically all of the metals used in technology are covered by a thin oxide layer of the metal which, due to its high shearing strength and brittleness, is not very effective as a lubricant but without it, welding and scoring of metal surfaces during friction would constitute a much more serious problem than they do now.

(d) Metals as Lubricants

In the beginning, it has been noted that, according to the Amonton Law, $F = As$, a reduction of friction is possible through the reduction of the values for A and s . This may also be achieved by the use of thin, soft metallic films on a hard metal base, as is shown in Fig. 17.¹⁹

In this case, the shear strength s is given by the shear strength of the soft metal, i. e., it is small and A also remains small, since the load is carried by the hard supporting metal, and a limitation is set to the increase of A by the given thickness of the thin metal film.

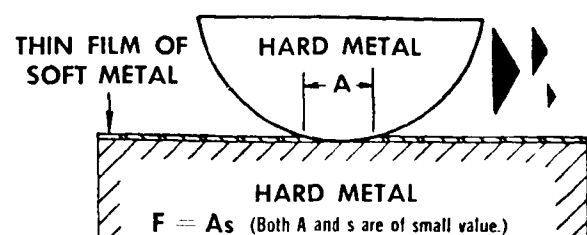


Figure 17. Principle of thin metal film lubrication

An increase in load, practically, does not result in an increase of A . Accordingly—deviating from the Amonton Law—with increasing load a reduction of the friction coefficient may be observed. For example, for an indium film on hard steel, at a load of 1 kg., a friction coefficient of 0.2 was measured, which dropped to 0.04 at a load of 8 kg. A limitation to the application is set by the fact that, under too high loads, the soft metal film is ruptured by the surface asperities of the steel bodies, increasing steel-to-steel contact occurs, and the lubrication by the soft metal breaks down. Additional factors, which determine the application limit of such soft metals are their melting points, the strength of their bond to the subjacent metal surface and the hardness and the surface structure of the latter.

A practical application for the lubrication by soft metal films is two-component bearing metals, such as copper-lead bearings, where during sliding the soft lead is smeared over the surface and behaves like a soft metal film on a hard base.

Indium, lead, tin, zinc, copper and barium have found practical applications for these purposes.

(2) Metal Organic and Organic Solid Lubricants

(a) EP Additives²⁰

The listing of EP additives under the term "solid lubricants" may be surprising but it will become intelligible from the standpoint of the action of these compounds. All chemical additives which are used in solution for increasing the load capacity of liquid lubricants, are effective only after reacting chemically with the metal surfaces. During this reaction, solid products are formed which are firmly bonded to the surfaces and contribute in the same manner to the reduction of friction as do solid lubricants. They form a solid film between the surfaces sliding on each other and the physical properties of this layer, such as shear strength and lateral cohesion, i. e., the bonding

forces between the molecules of the surface film, largely determine their effectiveness as EP additives. They show the advantage of being formed anew from the solution, to an extent at which they are lost as lubricants by abrasion.

These EP additives consist mostly of compounds containing lead, other heavy metals, sulfur, phosphorous, chlorine, or combinations of these elements. In many cases, under the influence of temperature and pressure from friction, the decomposing conditions of these compounds are reached, the decomposition products then react with the metal surface forming a strongly absorbed film which exhibits weaker shear strength than the metal and prevents metal-to-metal contact.

This decomposition of the EP additives and their reaction with the metal surfaces, noticeably occurs only at elevated temperature, as has been shown by measurements of additives with radioactive tracers.²¹ For this reason, instead of the term "extreme pressure" additives, the term "extreme temperature" additives has already been coined for these compounds.

A strongly idealized schematic presentation of the behavior of EP additives compared to ordinary mineral oils is shown in Fig. 18.

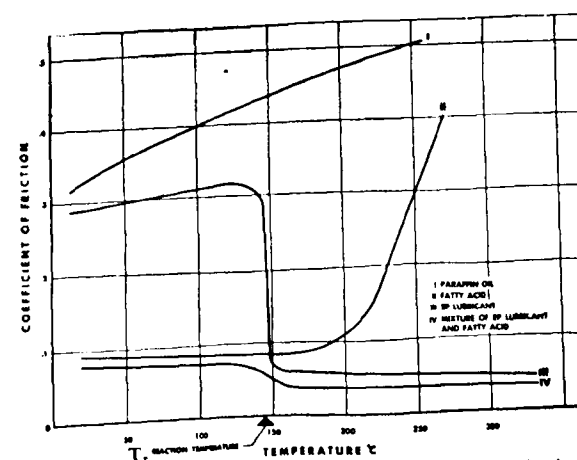


Figure 18. Simplified schematic frictional behavior of various lubricants as a function of temperature.

Curve I shows the behavior of paraffin oil. The initially high friction curve climbs with rising temperature. Curve II shows the behavior of a fatty acid which, due to soap formation with the metal, exhibits low friction values up to the melting point of the soap. Curve III shows an EP additive which reacts only very slowly with the surface at low tem-

perature. From a temperature T_r , marked reaction starts and good lubrication properties are assured up to high temperatures. Curve IV shows the advantages of both of them. Up to point T_r , the soap gives good friction values, then the EP additives assume this function.²²

This shows that, when producing EP oils, the selection of the additives must be made with great care. For, if very reactive compounds are chosen which react strongly already at normal temperature with the metal surface, severe attack on the metal surface will take place which is equivalent to severe corrosion.

In addition, the additives must be balanced with the types of metals which are involved in the lubricating action, since each metal has its own reactive tendencies with additives, different from those of other metals. Therefore, substantial differences in the effectiveness of EP additives when using different metals will occur.

Observing the actions occurring during starting or at very slow motion of machinery, it will be found that, at first, the sliding surfaces will have contact at very few points. High pressures, deformation of the metal, wear, and high temperatures occur on these spots. But for the EP additive it is already too late to become effective, since the surface asperities have already had contact, *prior* to the appearance of high local temperatures, which are a direct result of this contact. Only at higher velocities and high pressures will the average friction temperature on these contact surfaces be high enough to decompose the EP additives and to make a reaction of the decomposition product with the surface and the formation of an effective film possible. Therefore, other additive agents should be present which have a wear-reducing effect exactly in this critical range, at slow motion and low temperature, such as previously mentioned fatty acids or phosphate layers or solid lubricants dispersed in the EP oil, which may effect the separation of the surfaces in this range and may then, at higher temperature, i. e., at higher velocities, be supported by the EP additives.

In a manner similar to EP additives, attempts have recently been made to employ gaseous reactive lubricants at high temperatures, such as fluorine and chlorine substituted methane derivatives. In several cases, again dependent on the type of metals present, these gases prove to be effective lubricants, especially if adequate numbers of chlorine atoms are present to form a solid chloride film on one or both of the sliding surfaces.¹⁶

(b) Waxes, Fats, Soaps, and Fatty Acid Salts

This group of organic solid lubricants comprises all fats, waxes and soaps, such as aluminum-, calcium-, zinc-, magnesium-, sodium-, lithium-salts of fatty acids, paraffin wax, bees wax, candelilla wax, carnauba wax, fats like tallow, lard, and fatty acids, such as stearic acid and palmitic acid, etc.

These compounds are generally limited in their applications, mainly due to their relatively low melting point or, in the case of fatty acids, due to the melting point of the reaction products of these acids with the metal surface. They are applied in the form of solutions or rubbed on the surface to which they generally adhere very strongly. They are most extensively used in drawing and forming metals, where they are generally applied together with carriers, such as lime or phosphate layers.

(c) Plastics

When investigating the frictional behavior of plastics, it was found that Teflon, polytetrafluoroethylene, $(-CF_2-CF_2-)_n$ exhibits a much lower friction coefficient than all other polymers.¹⁹

While the friction coefficients of polymers may generally be compared with those of metals, Teflon²⁰ exhibits a much lower one. Its lubricity is not affected by liquid lubricants and, according to Bowden & Tabor, it remains unchanged up to a temperature of almost 300° C. The poor heat conducting properties of all polymers constitute a problem.

Lately, bonded coatings have been marketed with Teflon incorporated as a pigment and which are intended to make the transfer of the good lubricating properties of Teflon on numerous mechanical parts possible. A phenol resin is used as a binder. Actual practical proof is still missing. Likewise, homogeneous mixtures of polytetrafluoroethylene and graphite, molybdenum disulfide or metal powders are said to make a good lubricant for use at high temperatures.

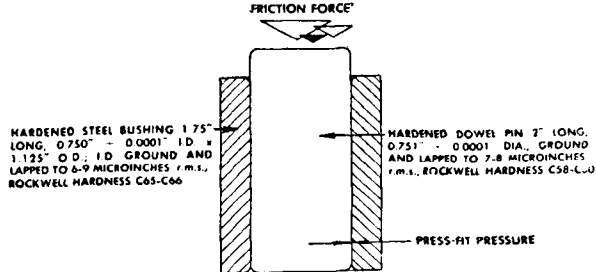


Figure 19. Press fit test.

As a simple, sensitive and reliable testing method, the press fit test²¹ was used for investigating many solids of some of the aforementioned categories. This test gives in a very short time information on the

Friction Coefficients of Various Solid Lubricants (Press Fit Test) Steel versus Steel			
Solid Lubricant	Friction Coefficient		Stick slip
	kinetic	static	
Inorganic solid lubricants with layer lattice structure:			
Molybdenum disulfide, natural	0.050	0.053	no
Molybdenum disulfide, synthetic	0.091	0.106	no
Tungsten disulfide	0.090	0.098	yes
Titanium disulfide	0.25	—	yes
Tellurium disulfide	0.25	—	yes
Selenium disulfide	0.25	—	yes
Graphite, natural	0.25	—	no
Graphite, colloid in water (22%)	0.100	—	no
Boron nitride	0.25	—	yes
Barium hydroxide	0.131	0.163	no
Lead chloride	0.191	0.214	no
Mica	0.25	—	yes
Silver iodide	0.231	0.245	yes
Talcum	0.25	—	yes
other inorganic compounds:			
Borax	0.210	0.226	no
Kaolin	0.25	—	yes
Rottenstone	0.189	0.195	no
Lead oxide/zinc oxide	0.25	—	yes
Vermiculite	0.160	0.167	no
chemical surface layers:			
Iron-manganese-phosphate layer	0.213	0.218	no
Iron-manganese-phosphate layer, molybdenum disulfide rubbed on	0.067	0.074	no
Sulfide melt (570° C) "Sulfimuz"	0.242	—	no

NOTE: A friction coefficient of .25 represents the maximum loading capacity of the test fixture used. Wherever .25 appears in the table above, a higher coefficient must be assumed.

Table 1

Table 1 continued

Solid Lubricant	Melting Point °C	Friction Coefficient		Stick slip
		kinetic	static	
Metal Organic and Organic Solid Lubricants				
Waxes and Stearates				
Spermaceti wax	43 to 49	0.048	0.062	no
Beeswax	60 to 63	0.050	0.055	no
Bayberry wax	44 to 49	0.054	0.070	no
Synthetic wax (comm. av.)	93 to 96	0.061	0.062	no
Polyethylene glycol (High MW)	53 to 56	0.077	0.078	no
Hydrogenated tallow glyceride	59 to 63	0.082	—	no
Candelilla wax	67 to 70	0.099	0.114	no
Paraffin	49 to 77	0.104	0.112	yes
Montan wax	78 to 90	0.108	0.120	yes
Carnauba wax	83 to 86	0.143	0.169	no
Diethylene glycol stearate	54 to 59	0.083	0.089	no
Calcium stearate	157 to 163	0.107	0.113	no
Aluminum stearate	129 to 160	0.114	0.119	no
Sodium stearate	198 to 210	0.164	0.192	yes
Lithium-12-hydroxy stearate	210 to 215	0.211	0.218	no

behavior of a lubricant, under the conditions of high load and low velocity and is mainly used as a preliminary test. Its work principle is shown in Fig. 19.

A slightly oversized pin is slowly pressed into a bushing and the resulting friction force is measured and possible stick slip behavior is observed. The tested solids and the results obtained are summarized in Table 1.

From this table, it becomes apparent—in agreement with industrial applications—that especially molybdenum disulfide, graphite, waxes, soaps, and phosphate coatings are suitable as solid lubricants.

At the end of this review on "Lubrication by

Solids," the importance of solids as lubricants may be briefly summarized:

In hydrodynamic lubrication solid lubricants are not necessary; lubrication is adequately provided by the liquid lubricant. In boundary and mixed lubrication, additives have been successfully used for a long time to reduce friction and wear, acting as true solids by reaction with the metal surfaces. In the same way, dispersions of solids in liquids have been increasingly used in lubrication and, for many purposes, dry solid lubrication has proved to be the only way of solving frictional problems.

Thus solid lubricants have become an integral part of lubrication.

LITERATURE REFERENCES

1) W. E. Campbell, "Solid Lubricants"; Lubrication Engineering, August 1953, 195-200; E. Robinowicz, "Solid-Film Lubrication"; Product Engineering, March 1954, 188-192.

2) E. Stribeck, "Die wesentlichen Eigenschaften der Gleit- und Rollenlager"; Z.D.I. 46 (1902): 1341-1348.

3) A. Sommerfeld, Z. Math. Phys. 50 (1909) 97; O. Reynolds, "On the Theory of Lubrication"; Phil. Trans. Roy. Soc. London A 177 (1886) 157; N. Petroff, "Neue Theorie der Reibung"; Deutsch von L. Wurzel, Hamburg und Leipzig, 1887.

4) F. P. Bowden, D. Tabor, "The Friction and Lubrication of Solids"; Oxford University Press London, 1954.

5) A. Sonntag, "Die Wirkungsweise von Schmiermitteln beim 'Einlaufen' neuer Maschinen"; Schmiertechnik 1958, 267-273.

6) H. Schornhorst, "Zahnradschaden im Betrieb"; VDI-Nachrichten 13 (1959) Nr. 4; G. H. Clark, "The Lubrication of Turbine Gearing"; Scientific Lubrication 11, (1959) Nr. 6, p. 19.

7) R. H. Savage, "Graphite Lubrication"; J. Appl. Phys. 19, (1948) 1-10; E. R. Braithwaite, "Graphite and Molybdenum Disulfide—Factors Affecting their Lubricating Properties in Reactors"; Nuclear Engineering, March 1957, 107-110; J. Boyd, B. P. Robertson, "The Friction Properties of Various Lubricants at High Pressures"; Trans. ASME 67 (1945) 51-56; W. S. Campbell, Rose Kosok, "Studies in Boundary Lubrication. The Wear of Carbon Brushes in Dry Atmospheres"; Trans. ASME 70, (1948), 491-498.

8) R. F. Deacon, J. P. Goodman, "Lubrication by Lamellar Solids"; Proc. Roy. Soc. A, 243 (1957) 444-462; B. L. Mordike, "The Lubrication of Solids at High Temperatures"; ASLE Meeting April 1959, Buffalo, N. Y.

9) E. E. Bisson, R. L. Johnson, M. A. Swickert, "Friction, Wear, and Surface Damage of Metals as affected by Solid Surface Films"; Conference on Lubrication and Lubricant-Research and Development; Air Force-Navy-Industry Lubrication Conference, Feb. 1959, Dayton, Ohio; V. R. Johnson, G. W. Vaughn, "Investigation of the Mechanism of MoS₂ Lubrication in Vacuum"; J. Appl. Physics 27, (1956) 1133-1134; Lubling, Felsig, "Lubricating Properties of Molybdenum Disulfide"; ASLE Meeting April, 1952, Cleveland, Ohio.

10) F. Hirano, S. Yamamoto, "Four Ball Test on Lubricating Oils Containing Solid Particles"; WEAR, Vol. 2, 1958/59, 249-263.

11) Long's Handbook of Chemistry, Handbook Publishers, Sandusky, Ohio, 1956.

12) E. E. Smith, "Molybdenum Disulfide as a Grease Additive"; NLGI Spokesman, Dec. 1956, 20-24; W. W. Kufman, "Die Wirkung von Molybdaendisulfid als Hochdrucksmittel zu Walzlagergerat"; Erdol und Kohle 9 (1956) 380; H. S. White, D. Zee, "Static Friction Tests With Various Metal Combinations and Special Lubricants"; J. Res. Nat. Bur. Stand. 46, No. 4, (1951) 292-298.

13) "The Coefficient of Friction of Molybdenum Disulfide-Silicone Mixtures"; "Molybdenum Disulfide as a Lubricant"; Climax Molybdenum Company, 1954, 66.

14) D. Godfrey, E. E. Bisson, "Bonding of Molybdenum Disulfide to Various Materials to Form a Solid Lubricating Film, I—The Bonding Mechanism"; NACA Tech. Note 2628, Feb. 1952; E. P. Kingsbury, "Solid Film Lubricants at High Temperatures"; ASLE Meeting Oct., 1957, Toronto, Canada; L. Berry, "Solid Lubricant Coatings"; ASME-ARS Joint Aviation Conference, Dallas, Texas, March, 1958.

15) R. L. Johnson, M. A. Swickert, E. E. Bisson, "Friction and Wear of Hot-Pressed Bearing Materials Containing Molybdenum Disulfide"; NACA Tech. Note 2027, Feb. 1950; Frictional Properties of Porous Metals Containing Molybdenum Disulfide"; Research, 3 (1950) no. 8; F. P. Bowden, K. V. Shooter, "Frictional Behavior of Plastic Impregnated with Molybdenum Disulfide"; Research, 3 (1950) no. 8.

16) M. T. Lovik, G. E. Gross, G. W. Vaughn, "Investigation of the Mechanism of Tungsten Disulfide Lubrication in Vacuum"; ASLE Meeting, April, 1957, Detroit, Mich.

17) M. T. Lovik, T. B. Daniel, "Development and Evaluation of High Temperature Solid Film Lubricants"; Midwest Research Ind. Quarterly Progress Report No. 1, 1959; R. L. Johnson, H. E. Giney, "High Temperature Friction and Wear Properties of Solid Bonded Lubricant Films Containing Lead Monosulfide"; ASLE Meeting, April, 1959, Buffalo, N. Y.; E. E. Bisson, R. L. Johnson, W. J. Anderson, "On Friction and Lubrication at Temperatures to 1000° F with Particular Reference to Graphite"; ASLE-ASME Lubrication Conference, Toronto, Ontario, Canada, Oct., 1957; M. E. Peterson, R. L. Johnson, "PbO and Other Metal Oxides as Solid Lubricants for Temperatures to 1000° F"; ASLE-ASME Meeting, Oct., 1956, Atlantic City, N.J.; H. E. Sliney, "Lubricating Properties of Lead-Monosulfide-Bare Coatings of Various Compositions at Temperatures to 1250° F"; NASA Memo 3-259 E.

18) A. A. Milne, "Experiments on the Friction and Endurance of Various Surface Treatments Lubricated with Molybdenum Disulfide"; WEAR, Vol. 1, Nr. 2, Oct. 1957, 92-103; W. Mochu, "Die Phosphatierung"; Verlag Chemie, Weinheim, 1950.

19) "Phosphating Treatments—Patent Literature Survey"; Metal Finishing, April, 1958.

20) US Patent 2,840,498, 1958; E. E. Logue, "Composition and Method for Producing Combination Corrosion Resistant Lubricating Coatings on Metals".

21) F. P. Bowden, D. Tabor, "Friction and Lubrication"; Methuen & Co., London, 1956.

22) C. V. Smolheer, T. W. Mastin, "Lubricant Additives and Their Action"; J. of the Inst. of Petroleum 42 (1956) 337-346.

23) E. H. Loesser, R. C. Wiquist, S. B. Twiss, "Cam and Tappet Lubrication III—Radioactive Study of Phosphorus in the EP-Film"; ASLE Meeting, April, 1958, Cleveland, Ohio.

24) Same as 19).

25) C. B. Davies, "A Review of Boundary Lubrication"; WEAR, Vol. 1, Nr. 1, 1957, 244-253; Brit. Patent 787,359; A. Blomex, S. B. Twiss, P. J. Wilson, E. J. Snyder, "Friction of Teflon as a dry Lubricant Bearing"; ASLE Meeting, April, 1957, Detroit, Michigan; A. J. G. Allan, "Plastics as Solid Lubricants and Bearings"; ASLE Meeting April, 1957, Detroit, Michigan; "PTFE Bearing Materials"; Modern Plastics, Feb. 1959, pp. 123-128.

26) A. Sonntag, "Solid Lubricants for Extreme Pressures"; Product Engineering, June 1959, 63-64.

£ 9.7 MILLION ORDER FROM SOUTH AFRICAN RAILWAYS

The South African Minister of Transport, Mr. B. J. Schoeman, has announced that an order to the value of £ 9,707,442 has been placed by the South African Railways with the Union Carriage and Wagon Company (South Africa) Limited of Nigel, Transvaal.

The order is for 113 electric motor coaches, 60 driv-

ing trailers, and 276 plain trailer coaches plus spares.

The new electric coaching stock, Mr. Schoeman said, was urgently required not only to meet expanding suburban and inter-urban passenger demands, but also to provide for increasing passenger requirements from non-White areas.

Brazilian Railway's 90th Anniversary

ONE of the biggest birthday packages on record was received by Brazil's Companhia Paulista de Estradas de Ferro recently in honor of the railroad's ninetieth anniversary.

Inside a plastic wrapping—complete with red bow and birthday greeting card—was a 68 ton, diesel-electric locomotive, sent by General Electric (U. S. A.) Company's Locomotive and Car Equipment Department in Erie, Pennsylvania.

The "gift" arrived with four other G-E diesel-electric locomotives—part of an order of ten made by the Paulista—in Santos, where Moore-McCormack Navegacao S. A. gave a luncheon aboard the "Mormacowl" for officers of the railroad, General Electric S. A., and the press.

The Paulista, known as "Brazil's Money-Making Railroad," is one of the best examples of Brazil's railroad system, and compares favorably with some of the world's best railroads in passenger comfort and speed of transportation service.

It was founded during the war with Paraguay in 1868 by Conselheiro Joaquim Saldanha Marinho, then president of the province of Sao Paulo. And nearly all the capital for starting the company was raised within the country—the biggest project ever undertaken without the aid of foreign capital up to that time, Globe Press Service notes.

Since then, the Paulista has had a record of good

management and foresight. It has delivered many immigrant-settlers into the interior of Sao Paulo free of charge to open up new land. And it has continually modernized and standardized its operations.

These policies have paid off. During all the years of its life, the Paulista has paid dividends—a feat rare in the history of railroads.

The new General Electric locomotives will shortly go into service hauling passengers and freight throughout the interior of Sao Paulo, between such cities as Santos, Jundiai, Bauru and Campinas, adding to Brazil's new re-equipment program for railroads.

Under this program, the Rede Viacao Parana-Santa Catarina recently began receiving delivery of the first of its order of 30 new G-E diesel-electric universal-type locomotives, bringing to a total of 88 the universal-type locomotives delivered or ordered from General Electric by various Brazilian railways in the past 18 months.

Guests present at the Paulista birthday party in Santos February 6 included Dr. Jose de Assis Ribeiro, president of General Electric S. A.; Dr. Jaime Cintra, president, and Drs. Durval de Azevedo, Clovis Soares de Camargo, and Joao Sampaio, directors, of the Companhia Paulista de Estradas de Ferro. Also present were officers of the Sorocabana and Santos a Jundiai railroads, as well as representatives of the Santos port and Moore-McCormack Lines.

distributor for India, to receive specialized training at various Worthington plants in America.

STEEL FOUNDRY AT CHITTARANJAN

The Deputy Minister for Railways, Shri Shah Nawaz Khan, replied in the affirmative to a question by Shri R. C. Majhi and Shri Subodh Hansda in the Lok Sabha whether negotiations had been completed with the technical collaborators in the U.K. for setting up a steel foundry at Chittaranjan to produce steel castings for railway track. He said that the final draft agreement had been drawn up and sent to Messrs. F. H. Lloyd and Co., U.K. for acceptance.

DIESEL-ELECTRIC RAILCARS

Details of BTH-Davey Paxman 450 h.p. equipment tested by British Railways

*By R. Bugler, M.A., A.M.I.E.E., A.M.I.Loco.E. BTH Traction Dept.
and R. R. Smith Davey Paxman & Co. Ltd.*

IN the late autumn of 1955, discussions took place between the Chief Mechanical and Electrical Engineer of the London Midland Region, British Railways, the British Thomson-Houston Co. Ltd., and Messrs Davey Paxman & Co. Ltd., on the design of high-speed railcars for use on fast inter-city services. In order to achieve the maximum possible passenger space, it was considered desirable to place all the equipment on the underframe of the railcars, and for this purpose the horizontal 6-cylinder railcar engine Type 6 ZHXL, made by Davey Paxman, was favoured. With a view to obtaining experience in railway service with this engine, and proving the advantages to be derived from this type of railcar, it was decided to build two trial coaches and equip them with diesel-electric propulsion equipment based on the 6ZHXL engine. The coaches were for test purposes only, and it was agreed that no fare-paying passengers would be carried.

It was realized that there was no existing design of underframe which was suitable for carrying such an engine-generator set, with a continuous output of 450 b. h. p. at 1500 r. p. m. Accordingly, with the close and enthusiastic collaboration of the Carriage and Wagon Engineer, London Midland Region, the following arrangements were made.

COACHES

Two passenger coaches built in 1926, and due for early scrapping, were stripped of all internal fittings. The flat underframe was reinforced by an arch-girder inside the body, to take the extra stresses entailed by the underframe mounting of the engine-generator set. The engine-generator set, (Fig 2), comprising the engine, main generator spigot mounted to it, and the belt-driven exciter, was mounted on rubber foot mountings on a cradle hung from the underframe of the coach. The radiator was also mounted on the underframe and had sections for oil and water. Cooling air was blown through the radiator panels by motor driven fans.

The bogies and traction motors were provided by the London Midland Region and were taken from the Watford line electric stock. New gears were necessary and were provided by BTH. All the remaining equipment was carried inside the body of the coach.

As finally constructed, the coaches formed a train weighing 103 tons. The available horsepower for traction was 440 per engine, giving a power-to-weight ratio of about 8.6 h. p. per ton. The maximum permitted speed was 85 m. p. h., limited by the traction motor speed.

ENGINE

The engine used for the tests was a six-cylinder unit of 7 inch bore and 7¼ inch stroke designed to give 450 b. h. p. (intermittent rating) at a speed of 1500 r. p. m. with the cylinders arranged horizontally in line. In this design, the combined crankcase and cylinder housing of corrosion-resisting high-strength aluminium alloy carries the underslung main bearings having deep-fitting forged aluminium main bearing caps. Pressed aluminium covers on the top face of the crankcase give easy access to the large end bearings and pistons; the underside is enclosed by a cast aluminium sump. Ample water jacket space is provided around the replaceable cast iron cylinder liners. Cylinder heads, cast in blocks of three, seat on the outer face of the main casting, each being fitted with two inlet and exhaust valves. The valve seats of aluminium bronze are particularly well cooled to reduce the need for attention and the fuel injector is centrally located. The rocker gear is carried on the outer face of the cylinder head and is force-lubricated from the main engine system. The cylinder heads are identical in all respects and interchangeable. The case-hardened steel camshaft is located in the lower part of the crankcase and is gear driven at the free end of the engine. The cams run in an oil bath and operate roller-type cam followers.

The pistons are one-piece aluminium alloy heat-

Worthington Appoints Indian Engineer to Caribbean Post

Kashmir-born Brij M. Chhabra has been appointed Worthington Corporation (U. S. A.) Resident Air Conditioning & Refrigeration Sales Engineer for the Caribbean area.

Chhabra, who will be based in San Juan, Puerto Rico, is an expert in industrial refrigeration. He went to the States about nine years ago as a student and joined Worthington in 1955.

The Indian air conditioning and refrigeration application engineer was initially assisted by Blue Star Engineering Co. (Bombay) Private Ltd., exclusive Worthington Air Conditioning & Refrigeration



treated castings having a central combustion chamber machined in the crown. Three pressure rings and one oil control ring are located above the gudgeon pin and one stepped scraper ring below. Connecting rods of heat-treated carbon steel stampings are accurately matched for balance and weight. All main and big-end bearings consist of steel shells lined with copper-lead and are lead plated. This process assists the initial running in. Bearings may be replaced without the necessity for fitting or scraping.

Forced lubrication is employed throughout by means of an externally mounted engine-driven gear-type pump. The pressure pump supplies lubricant to the main gallery and valve gear through a full-flow 'felt element' filter. From the main gallery lubricating oil is led to the main bearings and camshaft, and thence to the rocker gear. The system is designed to reduce the length of exterior pipework and retain full accessibility to filters and relief valves. A second pump of the same design circulates oil through the radiator and an Auto-Klean strainer. The use of the dual pump system protects the radiators from the high pressures associated with the single pump system.

The fuel pump is located on the bottom crankcase

cover and driven by a cardan shaft taking its drive through gears from the free end of the engine.

A plunger-type fuel feed pump is fitted to ensure an adequate supply of fuel under positive pressure to the fuel pump. The multihole fuel injectors are readily accessible and can be removed without disturbing the cooling water system. Contamination of the lubricating oil by fuel is impossible since the whole of the fuel system is located externally, thus providing maximum accessibility to the fuel pumps and injectors.

A centrifugal circulating water pump, also gear driven from the crankshaft, has a cast iron body, a stainless steel shaft, and a bronze impeller.

The engine was designed for coupling direct to an overhung flange-mounted single-bearing generator. The provision of a torsional vibration damper at the free end enabled the engine to run indefinitely at any speed within the running range without incidence of critical speed or torsional vibration.

An 'Ardleigh' servo governor was fitted for remote operation to give eight engine speeds, with torque control. A suitable overspeed trip mechanism which functions in the event of overspeed was fitted.

There was one exhaust-driven turbo-charger operating on the Buchi principle.

MAIN GENERATOR

This was a BTH Type RTB 7444 single-bearing overhung machine with exciter mounted on and belt-driven from it. The RTB series of machines has been specially developed by BTH for traction duty and rated in accordance with the requirements of BS. 173/1941. These generators are used extensively on diesel-electric shunting locomotives and for this application were taken directly from the production line with only minor mechanical modifications to make them suitable for coupling to the engine.

The continuous rating of the generator was 580 amp. at 520 volts. Mechanically, the generator is of rolled-frame construction with steel disc endshields, one of which carries the single bearing. Insulation of both field and armature conductors is full Class B, for which temperature rises of 120° C on armature and 130° C on field are permitted by British Standard 173. The machine is self-ventilated by a fan at the commutator end.

AUXILIARY EQUIPMENT

The time available for building these coaches precluded the construction of special auxiliary generators and D.C. motors for such duties as radiator fan motors, lubricating oil priming pump and compressor. It was decided to use standard 3-phase squirrel-cage induction motors, available from stock, and to supply them from a BTH 'Stavolt' alternator

driven by an auxiliary diesel engine mounted in the body of one of the coaches. This auxiliary diesel engine was a Ruston 4YE engine equipped with its own means of starting and was governed to 1500 r.p.m. and direct-coupled to the BTH 'Stavolt' alternator, which gave an output of 24 kW at 440 volts, 3-phase, 50 c.p.s., automatically regulated to close limits irrespective of the load on the alternator. As this supply was available, fluorescent lighting was also installed, making these trial coaches some of the best-lit vehicles on the London Midland Region.

ENGINE STARTING

Main engine starting was by motoring the main generator from the two batteries on the coaches connected in series, see Fig. 3. As the coaches were experimental and always manned by technical personnel, no alarm devices were provided, although the engine speed, lubricating oil pressure, and certain temperatures were indicated in the coach. For the same reason engine starting was non-automatic. The sequence when starting the main engine was as follows:—

- (1) The auxiliary diesel engine-generator set was started.
- (2) The battery isolating switches and the 'engine run valve' switches were closed.
- (3) The radiator fans were started.
- (4) The lubricating oil priming pump motor on one engine was started.

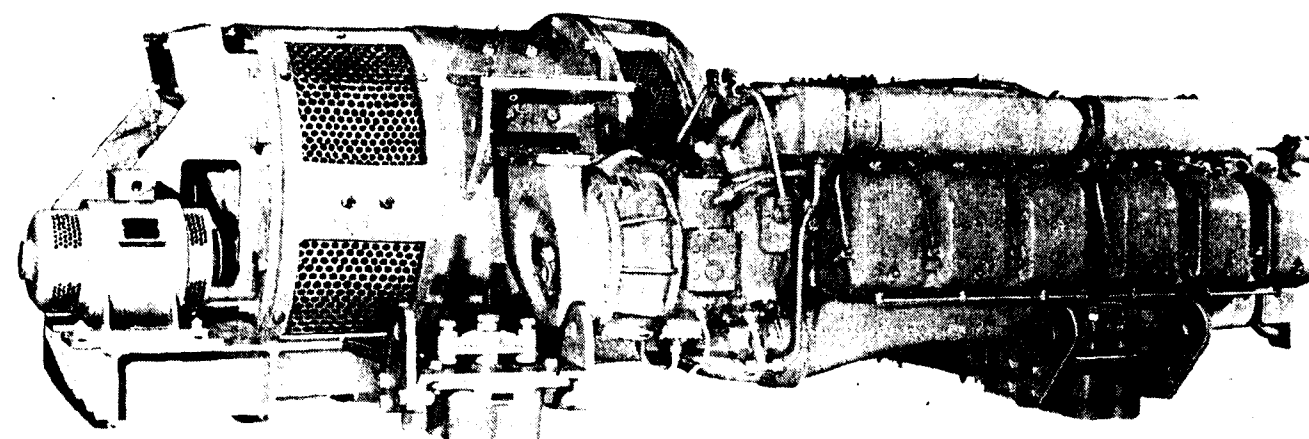


Fig. 2. The BTH-Paxman diesel-generator unit, as fitted to the railcars.

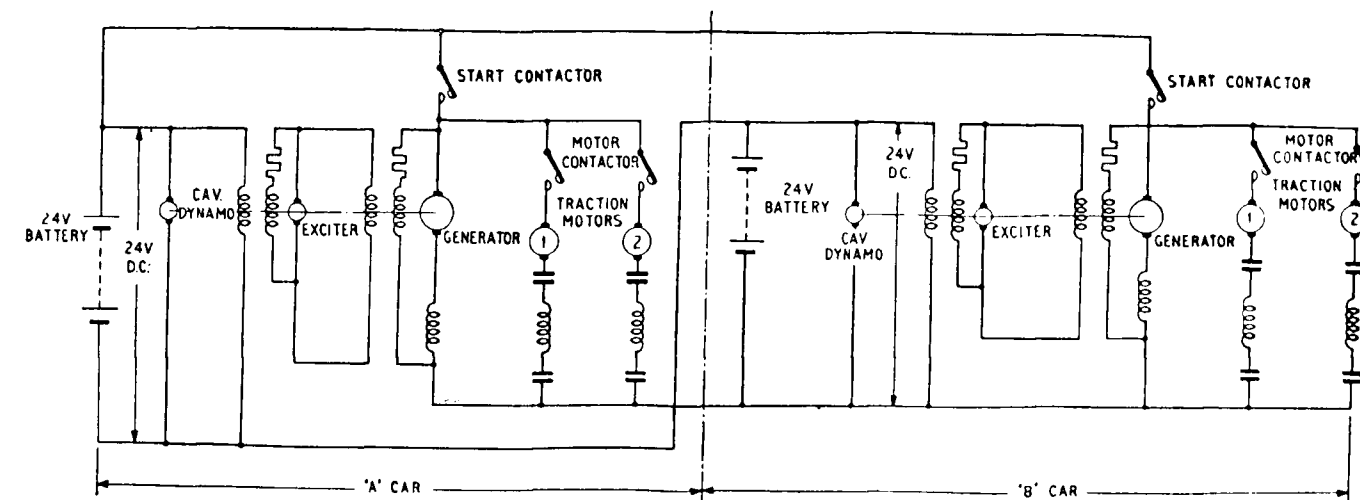


Fig. 3. In this simplified diagram are shown the principal connections of the power plant.

- (5) When oil pressure had built up, the 'engine start' button was pressed.
- (6) The engine was then motored by the main generator acting as a motor, and fired.
- (7) The lubricating oil priming pump was shut down, pressure being maintained by an engine-driven pump.
- (8) The sequence was repeated with the other engine.
- (9) The compressor was switched on.

The shutting-down procedure was even simpler:—

- (1) 'Engine run valve' switches were turned off, and the engine then stopped.
- (2) Battery isolators were opened.
- (3) All motors were switched off.
- (4) The auxiliary diesel engine generator set was shut down.

CONTROL SCHEME

One of the intentions of the BTH Company in designing the electrical equipment was to demonstrate the ease of control attainable with this form of transmission, and to show the impossibility of overloading equipment. It became quite normal for the drivers, after a little experience, to pull the power

handle immediately round to the top notch, and in this position the maximum acceleration was obtained smoothly and without any possibility of damaging the equipment.

These desirable features spring from the electrical scheme, which is based on the use of a speed-sensitive exciter and a 3-winding generator. The principles of this are well known, but briefly, the effect is to make the generator output characteristics follow the shape shown in Fig. 4. Over the middle range, where the generator is attempting to overload the engine, the governor moves up to its maximum fuel stop, and the engine speed then falls till the generator input and engine output again balance. The 'lost' horsepower due to this speed drop can be regained by the use of a load control rheostat driven by the governor, which adjusts the generator field system in such a way that the generator input balances the engine output at the full engine speed. Such a device is more useful in a locomotive which spends long periods at speeds in the middle of its range. It was, however, fitted to these railcars experimentally. The effect on performance was so small (since the cars spent most of their time at high speeds) that it was disconnected for most of the time the cars were running.

DRIVER'S CONTROL

The control system was deliberately kept simple. A supply of 24 volts D.C. was available from the battery on each coach, and in order to share the loads, the emergency lighting was taken from one coach battery and the control feed from the other, thus the coaches could only be operated when coupled together.

A driver's cab was constructed at the outer ends of the coaches, and this contained all the driving controls, but not the engine starting controls.

The driving arrangements were very simple. In each cab was a control switch, which energized the master controller in that cab. Each controller was unlocked by a Castell key carried by the driver, which mechanically released the forward/reverse handle. When this handle was in the off position the power handle was locked, but as soon as it was moved to forward or reverse the power handle was released, and the key was trapped. The power handle had eight positions, which controlled the engine speed via solenoids in the governor. In practice it was found that several of the intermediate notches were little used and it is likely that a production version would have less notches provided. An 'engine only' switch was also provided to enable the engines to be run up for testing purposes without power being applied to the traction motors.

RUNNING EXPERIENCE

The two cars were first run in September 1956, and after preliminary trials on the Wirksworth branch, embarked on a programme of testing which covered much of the country. It is only possible to record some of the highlights of this programme, but it may be said that over a period of about 17 months of continuous service, defects were negligible. The total mileage covered during this period was 43,267 miles. After completing this mileage, the main power units were thoroughly examined, and found to be without significant wear, giving a prospect of 500,000 miles of revenue-earning service between major overhauls.

Some interesting runs performed were:—

- (1) Two high speed trips from Derby to St. Pancras and back. Distance 129 miles, schedule 120 min. This schedule was met with about 5 min. to spare.
- (2) A run from Euston to Rugby, 82 miles in 78 min. This schedule was met with 2 min. to spare in spite of permanent way slacks accounting for at least 2 min.
- (3) Two runs from Derby to Gloucester and back, including a very fast climb of the Lickey incline at a steady speed of 36 m. p. h.
- (4) High speed runs from Sheffield to Kings

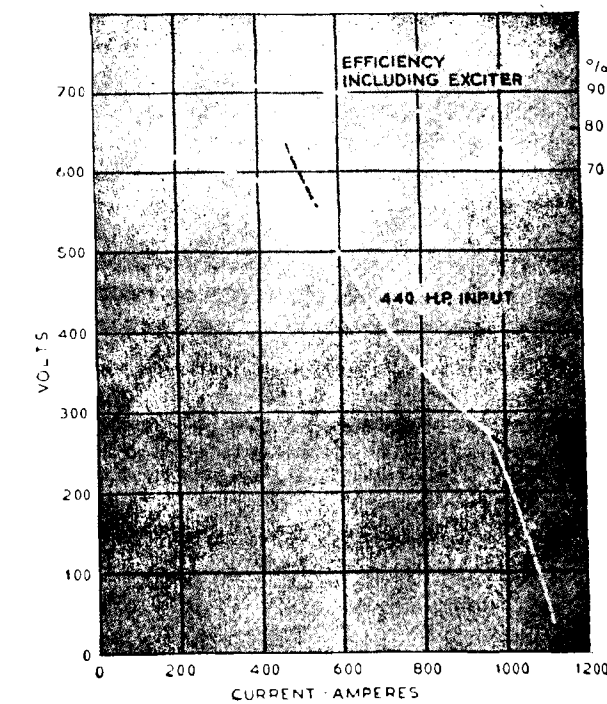


Fig. 4. The effect of a speed-sensitive exciter and 3-winding generator is shown by the curve of output characteristics.

Cross on the Eastern Region, a distance of 161 miles, in 161 min.

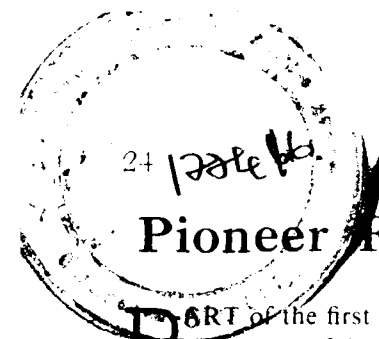
- (5) Continuous running over a fast schedule covering a daily round trip from Derby to Carlisle and back. This daily run was maintained for several months.
- (6) Runs from Liverpool to Bradford and back to a greatly accelerated schedule. This is the service for which the coaches were originally intended.

These coaches have conclusively proved the feasibility of mounting a 450-b. h. p. engine coupled to a generator underneath a railcar within the British Railways' C. I. loading gauge, together with the associated equipment. There is no doubt that such a railcar, having no passenger space occupied by equipment and with a high power-to-weight ratio, could be a versatile and valuable revenue-earning vehicle.

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Acknowledgements are made by the authors to British Railways for permission to publish this article.

The progressive and specialised development of rail traction type diesel engines over a period of 30 years has very largely contributed to the world-wide renown of Paxmans in this field of engineering. There is now available a comprehensive range of Paxman traction type diesel engines covering powers from 130-2300 HP. at rotational speeds varying from 850-1500 RPM.



Pioneer Fleet of Diesel-Electrics still going Strong

PART of the first fleet of diesel-electric locomotives to successfully operate on the Indian Railways is still giving good service in the Bombay area on the Western Railway.

Twelve 380 BHP, 44-ton General Electric (U. S. A.) Company diesel-electric shunting locomotives are currently being used for switching purposes in the big marshalling yards at suburban Bandra where they can haul loads up to 650 tons, on the main track, for movement from one yard to another.

These were part of an original order of 30 from the International General Electric Co. (U. S. A.) of such type locomotives obtained in 1945 under the wartime Lend-Lease aid from the United States Government to the British Commonwealth. Of the others, ten each went originally to the North Western Railway (now in Pakistan) and the former Great Indian Peninsular Railway (now the Central Railway).

Subsequently, each of the three railways sent two of the G-E diesel-electrics to the Bengal-Assam Railway and the remaining eight on the GIP eventually were transferred to the Bombay, Baroda & Central India Railway (now the Western Railway). Later, four of these 16 locos operating on this line were sent to West Bengal (three going to the Eastern Railway and one to the Chittaranjan Locomotive Works).

With a tractive effort of 27,000 lbs., these diesel-

electric locomotives are now identified in India as the WDSI class. Fitted with two power units, the maximum speed of this type is 35 m. p. h.

It is interesting to note that during a trial made in 1950 it was found that these G-E diesel-electric locomotives were suitable for working on the crowded main line of the WR to fast timings with a load of 6 coaches equal to 12 4-wheel units. However, they have not as yet been actually used for this purpose.

Western Railway officials disclosed to Globe Press Service that because all of these G-E diesel-electric locos are fitted with two power units they never have caused a breakdown blocking the main line. This is due to the fact that if one unit fails, the second one continues to work. They also stressed that, unlike the outmoded steam locomotive, these units can usually be put into service within half an hour after a requisition is received. That is the normal time it takes for the servicing of these locos.

In fact, the Western Railway reported that these G-E diesel-electric locomotives can be worked round the clock—if carefully handled—for a number of days without a break except for the half-an-hour servicing—all that is normally required for every 24 hours' operation.

Operated by an engineer and one assistant, these diesel-electrics can, on an equivalent, average 3,000 miles per month—mainly on switching service.

Testing New Locomotive Design in Rolling Laboratory

An experimental diesel-electric locomotive built by General Electric's (U. S. A.) Locomotive & Car Equipment Department will soon undergo exhaustive tests in a unique "rolling railway laboratory", the firm announced recently.

The rolling laboratory is a four-unit diesel-electric locomotive built by G-E and operated in regular heavy freight service by the Erie Railroad between upstate New York and Chicago, Illinois. It has been in operation since 1954 and has been used to develop and prove locomotive components under actual operating conditions on a main line railroad, Globe Press Service notes.

Many of the engineering refinements made possible by the unique laboratory on wheels have been incorporated into General Electric's line of universal-type diesel electric locomotives. These locomotives, which can be used in any type of railway service, are

currently in use on many major railways throughout the world.

The new locomotive design will be tested by using it in place of two units of the four-unit laboratory locomotive. This combination will then be operated as a three unit diesel-electric locomotive. The new unit will be periodically inspected by General Electric engineers.

The new unit will replace two 1200 horsepower units of the present laboratory locomotive. The remaining units are each rated at 1800 horsepower. The new three-unit set up will be controlled by one engineer in the same manner as the original four-unit rolling laboratory.

The new three-unit locomotive will be operated by the Erie Railroad. Like its predecessor, it will be used to evaluate advanced concepts of locomotive design and construction.

GOLDEN RULES OF CONDUCT FOR RAILWAYMEN

1. Do you plan your work daily? Get the more essential things done first and do not neglect the important ones sidetracking them to the fag end of the day.
2. Do not express casually careless opinion. Never venture forth an opinion unless asked for it.
3. Remember that most of our mental worries come either from trying to fight life hard or from trying to run away from life. Do neither.
4. Learn to accept people as they are, love them, respect them, praise them, encourage them, differ with them, but above all, learn the priceless art of give and take.
5. Cry neither for the moon, nor over spilt milk.
6. Accept the things that you cannot change; have the courage to change the things that you can, and possess the wisdom to know the difference.
7. Do not drive too hard a bargain with yourself.
8. Accept life as it is—its wonders, changes, disappointments, frustrations etc., etc.

CLEANLINESS LEADS TO HEALTH AND HAPPINESS

Clean orderly habits contribute to general health and welfare and as such to happiness and prosperity; they are more important than medicines.

Cleanliness prevents disease; medicine only attempts to cure.

Cleanliness of the person, of the houses and colonies, reflects discipline in the individual and the community. Discipline is the foundation stone for progress of oneself and the country. Cleanliness is a good habit. It is also cheap.

All Railwaymen should set an example of cleanliness. This will help others and themselves.