Chains for Power Transmission.

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(MEMBER).

THE Author approaches this subject, before an audience of automobile engineers, with considerable diffidence, because he recognizes only too well the position the chain occupies to-day to the automobile designer in comparison to what it did some few years back. Nevertheless, should the contribution result in the open and full discussion so characteristic of papers read before this Institution, he has little doubt the transmission of power by means of chains will substantiate its claim for continued recognition.

The historical aspect of the subject will not be dealt with to any extent, beyond mentioning that the development of really satisfactory chain gearing may probably be attributed, in the first instance, to demands made by the cycle trade. The roller chain for this purpose was introduced in 1880 by Mr. Hans Renold, and from this chain may be traced the practice, which has resulted in the commercial product now in use, and also the larger roller chains which are so extensively applied to general engineering purposes and to automobiles.

These chains have influenced to no small extent, especially in matters of construction, those which are later referred to under the designation of "Inverted Tooth Type." The standard half-inch pitch bicycle chain of to-day weighs 3 to 4 oz. per foot, has a breaking strength of 2,000 lb., and will run up to a speed of 800 ft. per minute, and under certain conditions even more, with satisfactory results.

Some idea of the accuracy required in building up such a chain may be appreciated when it is realised that a standard $\frac{1}{2}$ in. pitch cycle chain of 56 in. in length contains 560 distinct pieces, has 112 joints, and that the whole length is guaranteed within a limit of $\frac{1}{32}$ in., which only permits an average limit of ·0003 in. per joint.

This example, it is believed, will amply demonstrate not only the care which has been maintained in the manufacture of this type of chain and of all chain gearing generally, but also the proficiency which has been attained by manufacturers in its production. There has, in fact, probably been as much research and improvement of methods, both in regard to design and construction, in reference to the manufacture of driving chains, as in any subject occupying the minds of specialists.

Efforts have not been confined to the design and manufacture of the chain alone, for without at least equal study expended on the joint components of a drive (namely, the chain wheels), much of the work on chain design and construction would have been in vain. True it is that this side of the subject was for a long time much neglected, and treated by mechanical designers with but scanty consideration. However, for the last few years at least, thanks in no small measure to the insistency of the chain manufacturers, their particular importance has been generally recognized.

Before dealing with the application of chain transmission generally, the various types of chains will be considered; the selection of these is, in a great measure, governed by the speed factor.

Fig. 1, Plate XXIII., is the well-known Malleable Link Chain, introduced into the United States of America about 1870, which has commanded, and continues to enjoy, a considerable amount of success for slow drives, and, in conjunction with a great variety of specially constructed appliances, such as buckets, baskets and plates, &c., is used extensively in connection with conveying devices.

The work generally required of Stud Chains (Fig. 2, Plate XXIII.) is so slight that the rivets or studs are the only components required to be actually hardened; they are shouldered at the ends, and take their bearing in the actual link plates. Inasmuch as the fixed studs make contact with the wheel teeth, it naturally follows that this type can only be expected to prove satisfactory on very slow drives —say, up to 100 ft. per minute—and such chains are generally selected for balancing and lifting purposes, or for transmitting a reciprocating motion.

The unit from which the Block Chain (Fig. 3, Plate XXIII.) derives its name can be of any section to suit particular requirements. The pitch of alternate rivet holes in the outside connecting plates represents the pitch of the chain. The 1 in. pitch Block Chain which, in past years, was so popular on bicycles had respectively centres of ·4 and ·6 in. for the block and links.

The Block Chain is still largely used, and proves satisfactory up to speeds of 500 or 600 ft. per minute. All automobile designers know that this type of chain was generally used on motor cars in the early days, eventually being replaced by a roller chain constructed in such a form as to fit the wheels designed for the block type. Roller chains thus made are generally designated as "double roller." (Fig. 4, Plate XXIV.) Naturally, this type has a much smoother action than the solid block—due to the rollers revolving when in contact with the teeth.

Probably the development of the well-known Single Roller Chain (Fig. 5, Plate XXIV.) has helped more than any other to make transmission of power by chain as successful as we find it to-day.

Chain manufacturers, without exception, have devoted a great amount of care and study to design, in order to proportion the components to give the best results for hard wear and tear. It must be acknowledged that Single Roller Chains have proved of immense service in the past where speeds not greater than 800 ft. per minute were required, for they are particularly efficient and smooth in action, and permit of a comparatively inexpensive drive within their limits of speed. Chains of the Single Roller type are made in a great variety of pitches, varying from 8 mm. (5-16ths of an inch) up to 3 inches. (Fig. 6, Plate XXIV.)

The extraordinary wearing qualities of the Single Roller Chains, as evinced on automobiles working under anything but favourable conditions, warrant some reference to the material and methods of manufacture of their component parts. (Fig. 7, Plate XXIV.)

For many years the rivets were made of mild steel with shouldered ends, and case-hardened, the permanent fixing into the outside plates being performed with the ordinary hammer, thus necessitating a limit to their degree of hardness. Modern practice of the best manufacturers is to use a nickel steel case-hardened rivet, with recessed ends, the last feature permitting, with the aid of pneumatic hammers, a secure fixing of practically dead hard ends.

Bushes or sleeves are of mild steel of a good case-hardening quality, carefully reamered in the hole and machined on the outside to ensure concentricity.

The rollers are made of similar material to the bush, and are likewise carefully case-hardened to that degree which proves best to withstand shock and prevent liability to fracture when in actual use.

The side plates are blankings from a high quality of steel with a tensile strength of from 70 to 90 tons to the square inch, which has been cold rolled, and which is a particularly difficult material to work. The links are pierced within a limit of 0·0005 in. of the pitch and are reamered, the latter process being necessary in order to procure a perfectly smooth and parallel hole.

The rivets and bushes are a forced fit into the reamered holes of the outer and inner plates respectively.

Experience having proved the roller to be the first component to give out under hard wear and tear, the author, believing this to be due in no small measure to the grain of the material being tranverse to the diameter, designed the "Wormo" Roller (Fig. 8, Plate XXV.).

These are produced from a flat strip of metal coiled into tubes; the fibre of the metal, therefore, follows the circumference of the roller, and the chain is less liable to split or burst when in use. It is found that chains fitted with these rollers, on new wheels, are somewhat quieter than those fitted with rollers made from the steel bar, which is no doubt due to the peculiar method of construction.

With the object of reducing the components of single roller chains to the minimum, the integral form of alternate links (Fig. 9, Plate XXV.) is interesting.

The plate is originally a drop forging, machined all over to shape, so that when assembled the roller takes its bearing on the bush, or sleeve, which has been formed on the machined forging. This method of construction reduces the components by one-fifth, but the process of manufacture is obviously more expensive than in those chains previously described, and only meets a want where price is not the main consideration; the pull is steady, and the drive strictly in alinement.

The "Inverted Tooth Type" of Chain (Fig. 10, Plate XXV.) was originally designed for transmission of power at higher speeds than are suitable for roller chains. The former type has become increasingly popular, and meets the demands for chain drives developed by the electric motor and by high speed engines. Invented by one Guthrie, and manufactured by Messrs. Hans Renold, Ltd., of Manchester, they are now manufactured in this country by Messrs. Renold, The Westinghouse Brake Co., and "The Coventry" Chain Co. (1907), Ltd. It will be noted they are essentially link chains built up in series and with angular faces, the outer ones of which take a bearing upon the wheel teeth, which are cut to a constant conforming angle.

Undoubtedly, their chief feature is the fact that the links take a bearing upon the face of every tooth upon which the chain engages, and as the pitch of the chain increases, due to the inevitable wear of the rivet and the bush, or other bearing, the chain will ascend the angular faces of the wheel teeth, thereby assuming automatically an increased pitch circle, and thus accommodating itself to the wheel. (Figs. 11, 12 and 13, Plate XXVI.) A peculiar and distinctive feature of this type is the fact that power is transmitted by and to all the teeth in the arc of contact, irrespective of the increasing pitch due to elongation.

From the illustration (Fig. 11, Plate XXVI.) it will be noted that at no time does this chain take its bearing upon the bottom of the teeth, and that the links (Fig. 13, Plate XXVI.) have no sliding action on or off the teeth, but on the contrary lift themselves clear. This feature results in a gear with an extremely smooth and noiseless action, and one which can with confidence be recommended for speeds varying from 800 to 1,300 ft. per minute.

Manufactured in a variety of pitches, from 8 mm. up to 3 in., the type, general method of manufacture, and assembling, permits the manufacturer to vary the width without additional tool expense, and also permits of adaptation to transmit loads of hundreds of horse-power by a single chain. (See Figs. 14 and 15, Plate XXVII.)

The author is informed that there is now being constructed a chain of 2¼ in. pitch by 18 in. wide to transmit 350 h.p.; he is of the opinion that if he had such a proposition to deal with, he would probably be inclined to consider multiple units with balanced spring drive.

At the present time there are three distinct methods practised in order to ensure that these chains shall maintain their position on the wheels (Fig. 10, Plate XXV.). Originally flanged wheels were essential, but now either the overhanging side plates, or central guide plates running in grooves, are generally adopted.

When overall width of chain is not of vital importance, perhaps the outside guide plate principle is to be preferred, on account of its permitting the maximum area of wearing surface in a given working width of tooth.

Much attention has been given by chain manufacturers to the joint action of the bearings. Fig. 16, Plate XXVIII., will serve to describe the principle adopted by Messrs. Renold, Ltd., of Manchester. It will be noted that each hole in the plate has a small and a large recess; in the former the bushing is a fixture, whilst in the latter it has a clearance permitting the plates to swing on the studs. When assembled a fixture recess comes opposite to a clearing recess, thus permitting of angular movement, and as the bushings run the whole length of the studs, the wearing surface is continuous.

The Westinghouse-Morse Standard Double end Chain (Fig. 17, Plate XXVIII.) is on the rocker principle, with two hardened steel surfaces, the flat face of the one bearing on the edge of the other when the chain moves on or off the chain wheel.

Fig. 18, Plate XXVIII., shows the seat pin on the left and the rocker pin on the right. The movement taking place between the two is that of a hardened steel knife edge rocking on a hardened steel surface. It is claimed that sliding friction is eliminated, wear reduced, and a continuous bearing surface obtained.

The author is somewhat diffident in referring to the joint bearing of "The Coventry" Noiseless Chains, and will content himself by stating that he has consistently preached to his firm the value of simplicity in construction, as a reference to Fig. 14, Plate XXVII., will amply demonstrate.

Referring to chain drives generally, the chief points which will commend themselves to engineers are as follows:—

A chain drive is positive.

Its efficiency is high.

Tension is not necessary to make chains grip their wheels, as is the case with belts.

There is a minimum of journal friction, and, therefore, a more economical use of power than in any other mechanical means of transmission.

In the case of "Inverted Tooth" Chains, more quietness is obtained than with other forms of tooth gearing.

Whilst most contingencies in power transmissions can be met by the application of those types of chains already described, extreme cases where high chain speeds only are possible, and sometimes essential, prohibit the use of these.

Careful consideration led the author to introduce a high speed chain (Fig. 19, Plate XXIX.) to meet such exacting requirements, which although made at present in one pitch only, permits of varying widths dependent on the power transmitted. This chain can be run at speeds from 1,400 to 2,200 ft. per minute without detriment, and is practically noiseless at all speeds by reason of its distinctive tooth action, which, whilst resembling that of the roller chain, possesses the advantages of the "Inverted Tooth Type." The chain will drive on either side, and owing to its extreme flexibility and elasticity, can be used where crossed drives are required, if the centres are reasonably far apart, and the smaller widths of chain are used.

The formation of this chain approximates to that of the "Inverted Tooth Type," duplex plates forming a block, held together by a hardened steel bush which takes its bearing on a hardened rivet. The plates are of a special form, pierced with lightening holes, and the assembled chain is intended to be run on flanged wheels.

Chain drives occupy little space and overcome difficulties of cramped or awkward positions They give an efficient service at centre distances too short for belts and too long for gearing; they are climatically satisfactory, *i.e.*, under hot or damp conditions. They can be used for almost every kind of drive, but several factors determine the best size and type of chain to be used, among which are:—

The nature of the drive.

Whether the load is steady or intermittent.

The speed required.

The power to be transmitted.

No hard-and-fast lines can be laid down as to speed for any particular drive. Speed limits which can be recommended for each particular type have already been mentioned, but chains can be run at even higher speeds when special provision for lubrication is made.

The undoubted efficiency of chain gearing, as at present manufactured, is mainly due to:—

(a) The more thorough understanding of the principles involved, due to constant study of drives under working conditions.

(b) The many improvements in the manufacture of chains and wheels, which ensures the necessary precision.

(c) The more correct designing of chains and wheels, based on experience, and improved methods of mounting these details.

Given even normal conditions, the efficiency of chain drives is relatively higher than that of most other forms of transmission.

Under favourable circumstances, careful tests have shown that, for the chains only, an efficiency as high as 99 per cent. can be obtained, whilst for the complete drive, when well mounted, efficiencies of 96 per cent. and 97 per cent. have been obtained.

EFFICIENCY TESTS.

1 in. Pitch Single Roller Chain to equal Wheels of 11 Teeth.	$1\frac{1}{2}$ in. Pitch Single Roller Chain to equal Wheels of 8 Teeth.
1st Test.	
Speed, 890 ft. per minute; power transmitted, $4\frac{1}{2}$ h.p.; efficiency, 94 per cent.	Speed, 890 ft. per minute; power transmitted, $4\frac{1}{2}$ h.p.; efficiency, 91 per cent.
2nd Test.	
Speed, 880 ft. per minute; power transmitted, $7\frac{1}{4}$ h.p.; efficiency, 96 per cent.	Speed, 880 ft. per minute; power transmitted, $7\frac{1}{4}$ h.p.; efficiency, 96 per cent.
3rd Test.	
Speed, 870 ft. per minute; power transmitted, 10 h.p.; efficiency, $96\frac{1}{2}$ per cent.	Speed, 870 ft. per minute; power transmitted, 10 h.p.; efficiency, $96\frac{1}{2}$ per cent.
4th Test.	
Speed, 855 ft. per minute; power transmitted, $14\frac{1}{4}$ h.p.; efficiency, 97 per cent.	Speed, 855 ft. per minute; power transmitted, $14\frac{1}{4}$ h.p.; efficiency, 96 per cent.
5th Test.	
Speed, 840 ft. per minute; power transmitted, 17 h.p.; efficiency, 98 per cent.	Speed, 840 ft. per minute; power transmitted, 17 h.p.; efficiency, 95 per cent.

It will be noticed that as the speed of the chain decreases, and as the load goes up, so the efficiency increases.

It will also be noted that the conditions were not altogether ideal, inasmuch as the chain speed is slightly over what I have recommended in my Paper, and the number of teeth in each instance was small. It will be noted, however, that the efficiency of the $1\frac{1}{2}$ in. pitch roller chain averages about 3 per cent. less than that of the 1 in. pitch roller chain, due, no doubt, to the smaller number of the teeth of the wheels.

"THE COVENTRY NOISELESS" Chain, $\frac{3}{4}$ in. Pitch, working width 1·155, over two equal wheels of 18 Teeth.

1st Test.

Speed, 1,096 ft. per minute; power transmitted, $4\frac{1}{2}$ h.p.; efficiency, 94·5 per cent.

2nd Test.

Speed, 1,085 ft. per minute; power transmitted, $7\frac{1}{4}$ h.p.; efficiency, 97 per cent.

3rd Test.

Speed, 1,080 ft. per minute; power transmitted, 10 h.p.; efficiency, 97·5 per cent.

4th Test.

Speed, 1,059 ft. per minute; power transmitted, $14\frac{1}{2}$ h.p.; efficiency, 97·5 per cent.

5th Test.

Speed, 1,053 ft. per minute; power transmitted, 17 h.p.; efficiency, 98·5 per cent.

The above gives an average of 1,075 ft. per minute. The drive, therefore, would be under fairly ideal conditions. It will be noted that the efficiency rises with the load, in the same manner as with the roller chain, and appears to be about 1½ per cent. better than that of the roller chain.

Conditions of Test.

Motor, 20 h.p. B.T.H. 2-phase slip ring, connected in circuit to a 2-phase wattmeter to read the power consumed.

Brake.

Eddy current type, by Morris & Lister, of Coventry. The exciting current for this was supplied by a motor generator at 110 volts continuous current.

The first step was to determine the efficiency of the motor, which was done by coupling the motor direct to the brake. Five readings were taken at different loads, the load on the brake having been adjusted, the brake balanced carefully by means of the controlling rheostats, and the wattmeter reading and speed observed at the same time. This gave a curve for the motor efficiency at the different loads.

The brake was then driven by the motor by means of one of the chains, and the brake loads, speed, and wattmeter readings again observed with the same load on the brake as when testing the motor. In order to eliminate errors, due to wind resistance, etc., the sprockets used were of equal size, so as to drive the brake at the same speed as when coupled to the motor. The efficiency was thus determined from the wattmeter readings, corrected for the loss in the motor previously determined, and the h.p. as determined by the brake.

While maintained efficiencies of 94 per cent. to 96 per cent. are the rule for well-designed drives under average conditions, several factors must always be considered to ensure such results, among these being:—

(1) Speed of chain.
(2) Ratio between wheels.
(3) Position of drive.
(4) Efficiency of lubrication.
(5) Distance of centres.
(6) Proportions of the chain and wheel teeth.
(7) Nature of load, whether continuous or fluctuating.
(8) Size of chain relative to power transmitted.
(9) Design of bearing.

Seldom do chains prove too weak for the work required of them, for they will usually wear out by elongation, due to wear between rivet and bush, before breaking; therefore, selection should be made which postpones such a condition as long as possible. Other conditions being normal, it naturally follows that the life depends

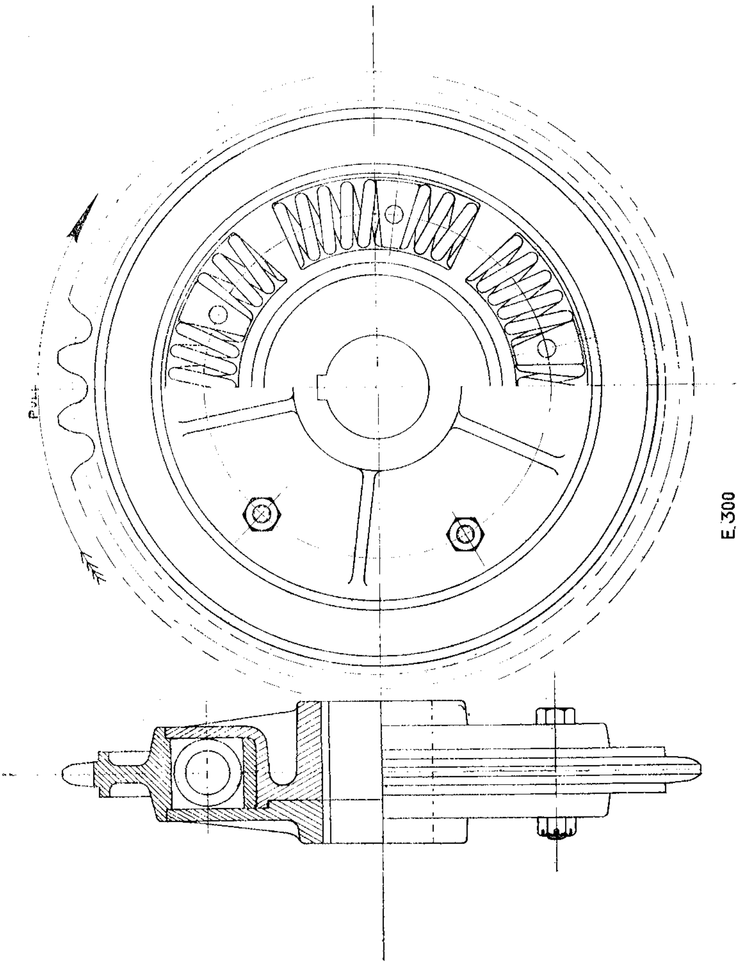


FIG. 20.—Coventry Shock Absorbing Spring Wheel.

on the amount of pressure per square inch of projected rivet area, and the hardness of wearing surfaces. It is found, in practice, that not more than 650 lb. pressure to the square inch of such projected area should be allowed.

As the wear and the strength of well-proportioned chains have a relation to the rivet diameter, it is customary to select them by their strength, instead of calculating the bearing surface of the rivet.

It would be somewhat dangerous to state here definite factors of safety for each particular type of chain by simply taking as a basis the breaking load and its ratio to the pull, for, obviously, the factors must vary, not only with the speed, but with the general conditions prevailing. For instance, with a short drive in a polishing or grinding shop the factor might conceivably be as high as 35 or 40, yet exactly similar chains might be used under ideal conditions of lubrication and speed, with a factor as low as 8 or even 5.

As a general condition it might be fair to state that if the lubrication was as good as is usually provided for the small end of the connecting rod of an engine which works under similar conditions to a chain bearing, equally high pressures per square inch of projected area might be adopted.

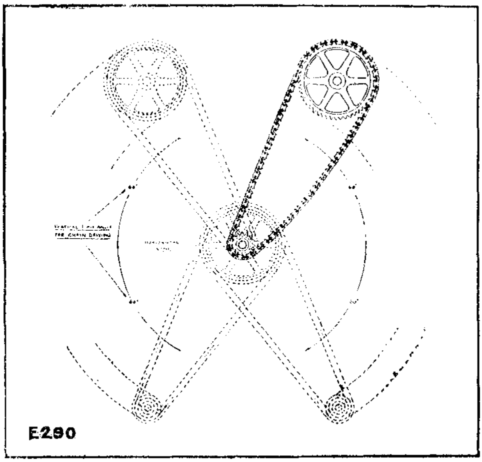


FIG. 21.

As in many other matters, automobile chains well above their work are more economical than those having a low safety factor, which accounts for the use of so large a factor in severe cases where the conditions of load are irregular.

For such drives, the chain manufacturers recommend the use of a shock absorbing wheel (Fig. 20), which has springs between the rim and the hub. These absorb the fluctuations of the load and prevent injury to the chain and wheels.

The highest ratios of wheels desirable between the driver and driven are :—

Inverted tooth type, 1 : 6.
Roller and block type, 1 : 7½.

The maximum and minimum numbers of teeth advisable may be said to be :—

Inverted tooth type,	15 and 90.
Roller type,	8 and 70.
Block type,	6 and 60.

Wheels of reasonably large diameters are to be preferred for quietness of running, and provision should, when possible, be made for a "hunting" tooth on one of the wheels. The position of drive

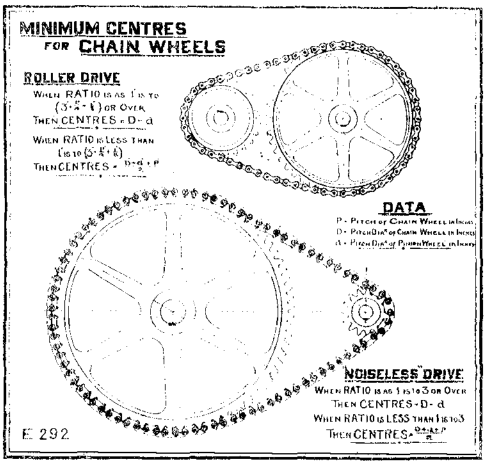


FIG. 22.

is of considerable importance—the chains should be run in a vertical plane, that is to say, the two shafts horizontal. If one shaft is higher than the other, the shaft carrying the larger wheel should be uppermost in order to distribute the weight of the chain over the greater number of teeth.

Fig. 21 indicates the approximate limit of vertical angularity at which a chain should be run without necessitating the introduction of a jockey pulley, but this will vary slightly with the direction of pull. In the case of vertical drives, however, in order to reduce the destructive element on both chain and wheels, by keeping the former in proper contact with the lower wheel, it is advisable to provide for a jockey pulley on the slack side. (Fig. 44, Plate XXXVII.)

Where possible the distance of the centres apart should not be less than one-and-a-half times the diameter of the large wheel, or greater than from 10 ft. to 12 ft. for fairly heavy drives.

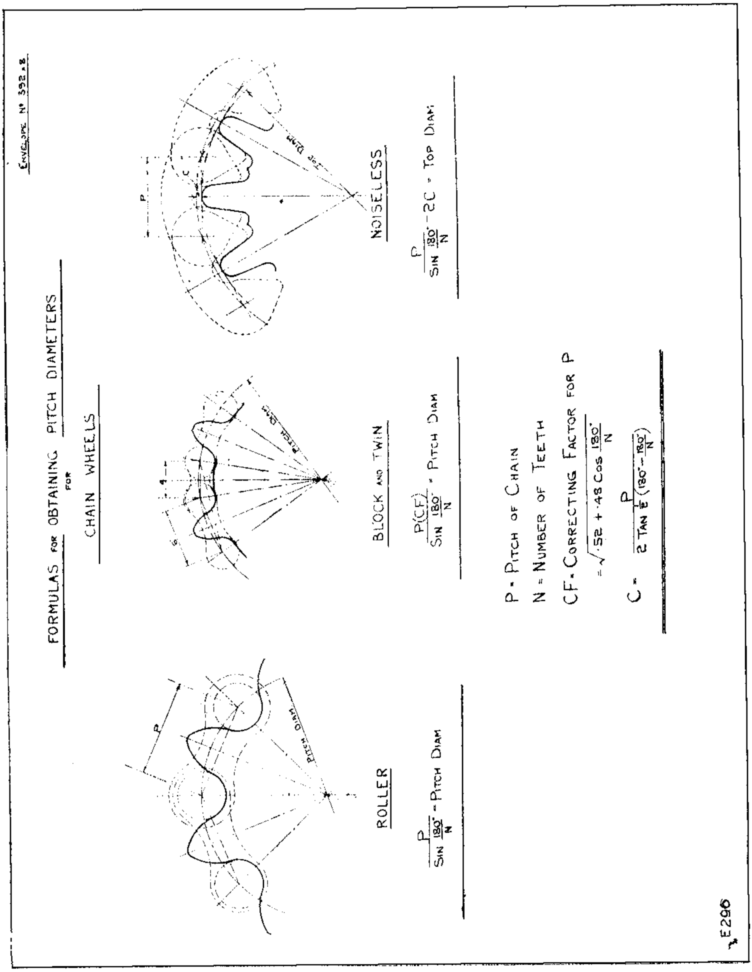


FIG. 23.

For elevator and carrier chains, which run on supports, the centre distance may be almost any length.

Although chains have a certain amount of lateral flexibility, and give satisfaction where the conditions are far from ideal, the general mounting, or erecting, cannot be too substantial. Shaft bearings should be rigid and wheels lineable. If on light shafts, liable to spring under load, the wheels should be mounted near the bearing. Exact alinement is essential for good results, and when the drive is from an electric motor, the minimum amount of end play in the armature is permissible.

It may not be out of place to say that the alinement of chains is not of such vital importance as with double helical cut gears, or worm drive.

Ordinary engineering factory drives running under fair conditions, should be lubricated once a week at least, with a lubricant free from any tendency to thicken. Where the temperature is much above normal a thick oil of considerable body should be used. When a more fluid oil is used its consistency should be judged by the speed of the drive. For high speeds use a thin oil in order to penetrate the joints, followed up by a thicker oil, which refuses to be thrown off by a centrifugal force. The lubricant is best applied with a brush to the inner side of the chain when stationary.

The advantages of providing a suitable cover, preferably of metal, will be obvious, and a drip lubricator should be fitted into the top portion with a tap in the lowest part of the guard, for draining away the oil when necessary.

Formulæ for Calculating the Diameter of Chain Wheels.

Block type
Single roller type
Inverted tooth type } FIG. 23.

It should be noted that for wheels suitable for block and twin roller chains the top diameters of the chain wheels are equal to the pitch line diameter, plus the diameter of the end of the block or the roller, while for single roller chains the top diameter should never exceed the pitch diameter, plus half the pitch of the chain. In the "Inverted" tooth chain the diameter of the wheel blank is, for all intents and purposes, equal to the pitch line.

It is advisable, but not absolutely necessary, to make provision for means of adjustment. It will be apparent that both tight and slack chains are evils to be avoided; as a matter of fact, only a small amount of slackness should be perceptible when the drive is stationary. Where no adjustment can be provided the chain should be shortened by one pitch as soon as the sag will allow; for this purpose special links are generally obtainable.

For wheels running at high speeds and with a small number of teeth, a good quality of mild steel should be used, the teeth being case-hardened.

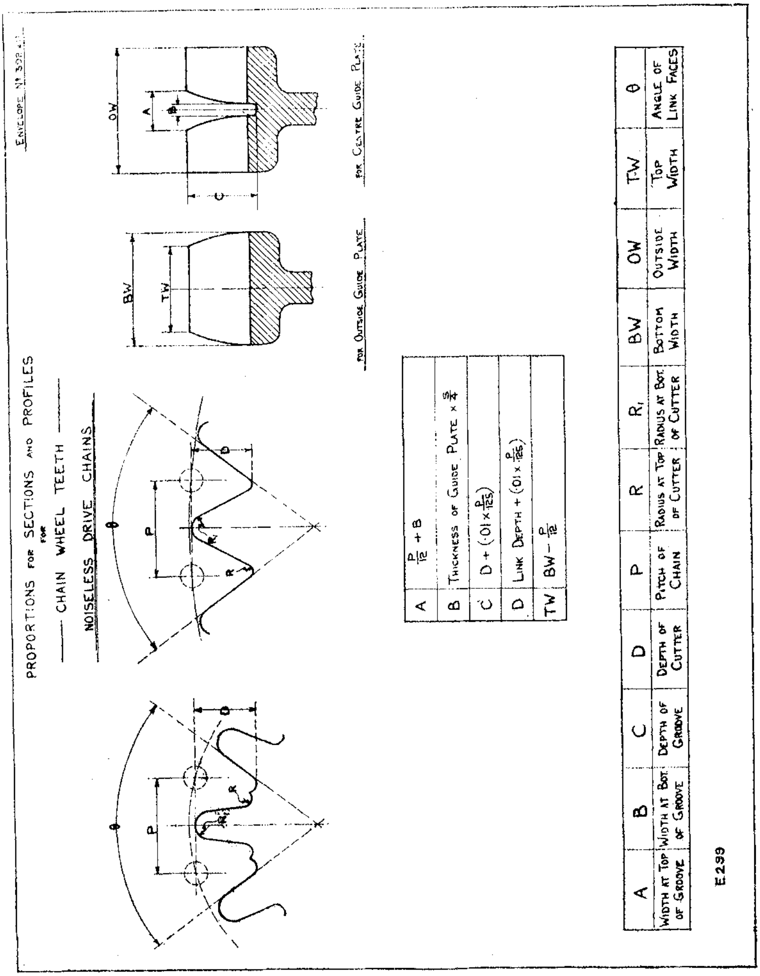


FIG. 24.

For the larger sizes a good quality of cast iron will usually be found suitable, except where the conditions are unusually severe, when steel castings may be substituted with advantage.

To maintain efficiency the continuance of correct tooth form of the chain wheels is essential. (Figs. 24, 25 and 26.)

Chain drives in connection with automobiles were generally acknowledged, by the original designers, to be a ready and convenient means of providing for the transmission of the power

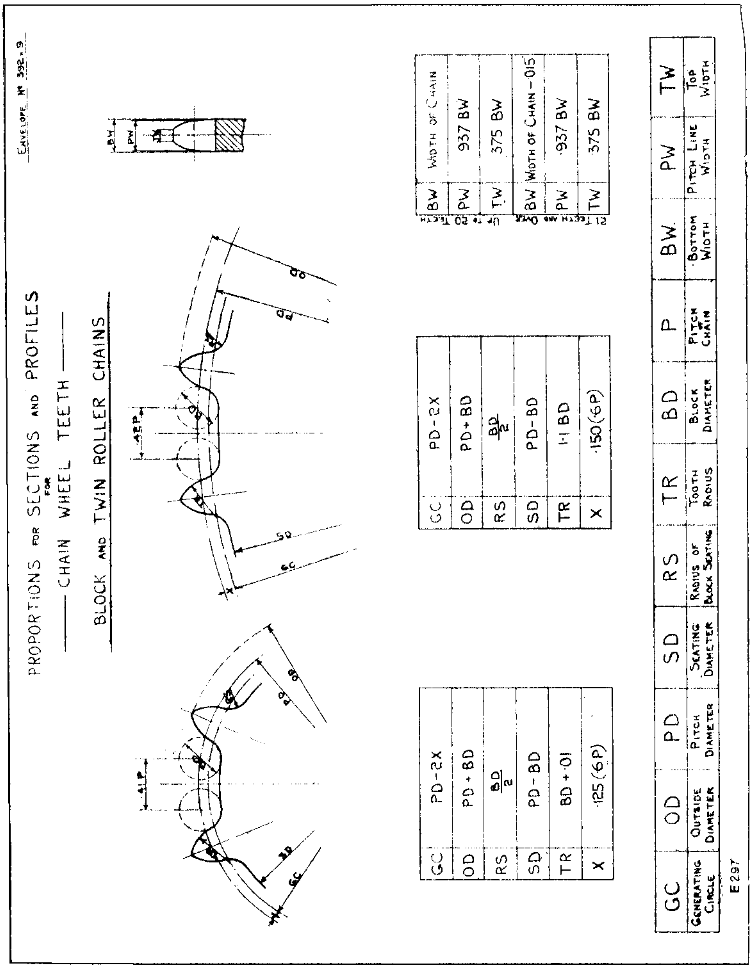


FIG. 25.

to the road, wheels, and to the chain must be credited no small part in the early development of the motor vehicle.

All of us doubtless recollect some of the early types of chain-driven cars with driving chain wheels having as few as 6 teeth, which quickly lost their original form and became under-cut or "hooked" (Fig. 27), causing constant chain troubles. As time went on matters somewhat improved, and the makers of motor vehicles

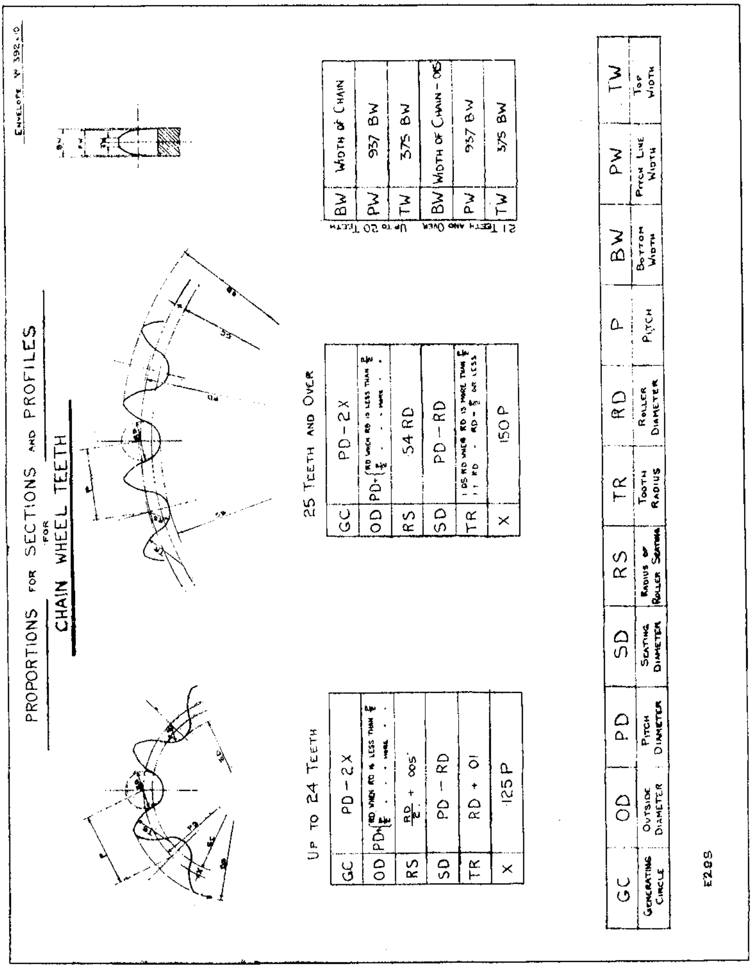


Fig. 26.

were so progressive as to put 9 teeth in the driving pinions with certainly better but yet far from satisfactory results.

It will be conceded that at this time chain manufacturers made marked advancement towards perfection of manufacture, especially in the life of the bearing surfaces, notwithstanding which, chains were rapidly destroyed, and the owners of automobiles bought new chains often without a thought of the wisdom of renewing the chain wheels; thus the new chains were compelled to get out of pitch even more quickly than the old ones which they had replaced.

Gradually the motor car manufacturers learnt by experience that if the wear was distributed over a greater area, the teeth would retain their correct form for a longer period, until eventually gears were being used with pinions having as many as 20 teeth and made of steel castings, or of mild steel, case-hardened, instead of bronze or malleable iron.

The above remarks, as far as chain wheels are concerned, have been confined to the driving pinions, because in nine cases out of ten they were mainly responsible for chain troubles.

Noise of transmission was reduced as the important conditions here detailed received attention, and the next improvement was

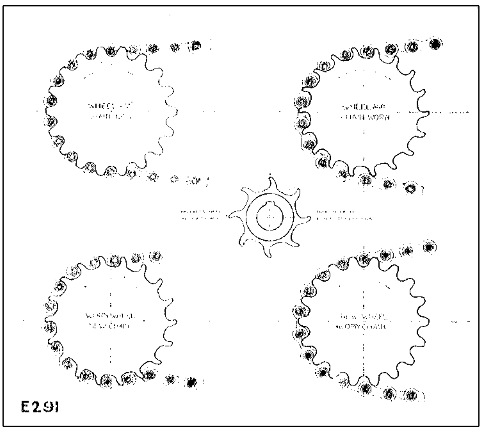


Fig. 27.

naturally the provision of means for properly encasing all chains and giving them a fair chance to prove their efficiency.

During all this time the fact must not be lost sight of that the horse-power of the engines of automobiles had rapidly increased, as much as 40—50 h.p. being transmitted through a pair of $1\frac{1}{4}$ in. pitch chains of the single roller type, whereas previously the same size of chain was being used for 6—9 h.p., and yet on the more powerful machines, under the improved conditions, the chains lasted much longer than on the lower powered vehicles.

Results have been recorded of 18,000 to 25,000 miles with one pair of chains. Is it too much to say that chains and chain wheels were probably the most ill-used part of the mechanism of a car? Their very position subjected them to streams of mud or dust from the road wheels, and nothing more could be expected of such an accurately made piece of mechanism working under such unfavourable conditions.

No doubt automobile designers have many awkward problems to solve, and unquestionably one is the designing of a proper chain case permitting cleanliness and reasonable lubrication. (Fig. 28, Plate XXIX.) At last, several automobile manufacturers decided to so design their vehicles as to admit of suitable chain cases being provided, and the author is of the opinion that chain gearing, under these conditions, compares with distinct advantage as regards efficiency, and most favourably as regards silence, with live axle cars.

It was to be expected that automobile designers would look for other means of transmission on their vehicles, in view of the unfortunate experience of many chain users in the early days, and there was great inducement to manufacturers to spend time and money in the endeavour to perfect the live axle. All are agreed that they have succeeded in producing a piece of mechanism which does them infinite credit.

No doubt troubles of no mean order were experienced in the development of the live axle, and who can say that if the same amount of time, patience and money had been devoted to the further improvement of the chain drive there would be anything like the same disproportion in numbers between live axle and chain driven cars as now exists?

The live axle, no one will deny, forms a clean and well-housed piece of mechanism, but do not its benefits end here?

It is not too much to claim for chains a higher efficiency for transmitting power than high reduction bevels or worm gears. Positive in their nature, they have some degree of flexibility, and even when fitted in cases they are fairly accessible.

Chains and chain wheels can be quickly renewed without great expense, and an alteration of gear ratios can be easily effected, to suit the particular district the car is generally required to travel in.

The flexibility of the chain drive permits of freedom for axle, spring, and frame movement, without setting up undesirable strains, and enables the road wheel, when required, to be conveniently splayed.

With the live axle practically the whole of the considerable weight of the bevel drive rests directly on the tyres, that is to say, the weight is not spring supported, with the result that the tyres on the rear wheels generally wear much more rapidly on a car with shaft gear drive than on a car with double chain drive. One pound weight added to the axle is harder on both tyres and axle than many pounds added above the spring.

The application of chain drives to heavy motor lorries and tractors simplifies many of the problems connected with the design and running of these particular vehicles, and permits of a drive which meets the most exacting requirements.

During the period when the chain troubles previously alluded to were sufficient to make an impression, there were very few commercial motor vehicles in existence, and by the time commercial cars began to command general attention, the chain drive had been greatly improved, and designers generally realised the importance of good chain wheels with correctly formed teeth. It will doubtless now be conceded by the majority of automobile engineers that the chain drive for commercial vehicles has demonstrated its superiority to the live axle, and there is little prospect, at present, of its being superseded.

The torsional strain put on the frames of this class of vehicle is very considerable, but this distortion does not injuriously affect the chain to any appreciable extent.

The fitting of chains as a means of transmitting power to the driving wheels of such vehicles at once dispenses with the large and heavy axle case with split axle, necessary when gear drives are employed, and permits of the use of the only satisfactory axle that can be used for carrying heavy loads, namely, a solid one. While thus reducing the total unsprung weight on the driving wheels to a minimum, a relatively stronger axle can conveniently be fitted, and the removal of the differential gear to the driving end of the chains, where it is protected from road shocks and axle strains, allows of a lighter gear being fitted, by reason of the increased speed at which it transmits the necessary power; incidentally also this arrangement permits of more efficient lubrication there.

Axle clearance with gear drives is very limited, but with chain drives to the road wheels it is easy to obtain an axle clearance practically equal to half the diameter of the driving wheels. The size of the road wheel, with chain transmission, can be made suitable to carry the required load, without being influenced by the ratio of reduction between the gear box and axle, by reason of the wide limits of ratios possible with this type of drive. The ratio of reduction can at all times be conveniently altered to suit varying conditions of road service, by the changing of sprockets and detachment or addition of one or more chain links.

With the chain drive torque rods are not required, and the absence of universal joints provides a transmission with an efficiency higher and more easily obtained and retained than is possible with other forms of mechanical drives.

To automobile designers of the present day, in order to get best results from chain drives to the wheels, the author would submit the following points :—

The pinion wheel should have from 17 to 20 teeth to suit chains of the "Inverted" tooth type for preference, and of a pitch and width suitable for the weight of the vehicle and power to be transmitted.

The ratio of wheels should not be more than $2\frac{1}{2}$ to 1.

The pinion wheel should be of mild steel, case-hardened.

The larger chain wheel, or wheels, should be made of steel castings, or mild steel, case-hardened, and for preference should be in the nature of a simple ring to bolt on to the brake drum.

The automobile designer should consult with the chain manufacturer as to correct tooth forms and wheel diameters. The whole chain gear should be cased in with a strong case easily detachable (Fig. 28, Plate XXIX.), or easily accessible, and provision should be made for a drip lubricator on the top of the case which should only drop oil on the chain when the car is in motion.

Such a drive would compare favourably for silence with, and would be less severe on the tyres than, the live axle. It would be cheaper to instal, would have longer life and permit easier alteration of ratios.

Although heated controversy resulted from the application of the "Inverted Tooth Type" of chain to the camshaft drive of petrol motors, the results obtained have amply justified the expectations of both manufacturer and user.

Coventry "Noiseless" chains were fitted to the two "Knight" Daimler engines (Fig. 29, Plate XXIX.) used in the now famous test carried out by the R. A. C., and some details regarding the condition of these, after running constantly at a speed of some 1,000 ft. per minute under their maximum load, may be interesting and instructive.

The two chains used were of $\frac{5}{8}$ in. pitch, and on completion of the test were found to have elongated in their total length of 42 and 43 pitches by $\frac{3}{64}$ in. and $\frac{1}{16}$ in. respectively, this difference being due to the fact that the former chain was used on the 22 h.p., and the latter on the 38 h.p. engine.*

The wear on the link faces was such as to still leave the marks of machining visible, and the average wear on the bush and rivet diameters was 0·0005 in. and 0·0006 in. respectively.

An equivalent road mileage under such severe conditions as the above test would approximate to 7,000 miles, during which distance the chain would have itself travelled over the wheels some 8,000,000 ft.

It will be noted that the centres of this drive (Fig. 29, Plate XXIX.) are particularly close—no adjustment is provided, and the conditions generally are extremely stringent. Should the chain elongate more than $\frac{3}{16}$ in. in a length of 25 in., its usefulness for this special purpose would probably be expended. For this particular drive every chain is required to be within the total limit of 0·02 in. in its total length.

Many firms are now considering the chain drive for the ordinary cam shaft, and in each case where tests have been made all the success expected of it has been realised. In every case it has proved, beyond question, to be quieter than spur gearing.

The chain driven gear box as fitted to the motor omnibus is somewhat of an innovation.

Fig. 30, Plate XXX., shows a chain gear box fitted to a London omnibus. Spur gears having proved noisy, the chain manufacturer came to the rescue, and the scheme has proved a great success; although the initial gear has not run more than 5,000 miles, there is every indication that it will prove to have a considerably longer life than the spur gears which it has displaced.

The magneto drives come under the heading of the minor uses to which the chain is applied on motor vehicles. As small a chain as 8 mm. pitch of the roller type can be used with excellent results on motor bicycles. It is now common practice to have these chains neatly enclosed in a case, which adds to efficiency and general appearance. (Fig. 31, Plate XXX.)

Both the ordinary bicycle roller chain and $\frac{1}{2}$-in. pitch "Inverted Tooth Type" of chain are being used for magneto driving on the automobile; the same types of chains are being used also for pumps, fans, and for driving small dynamos for producing electric light.

* In the paper as read these figures were interchanged. See discussion, p. 342.

In conclusion, the author ventures to suggest that there is a future for a chain-driven motor-bicycle by using a light "Inverted Tooth Type" of chain in connection with a shock-absorbing wheel, resulting in a more efficient transmission of power than can be obtained by the present method of belt drive on grooved pulleys.

The author desires to express his sincere and grateful thanks to Messrs. Hans Renold, Ltd., and the Westinghouse Brake Co., for their descriptive matter relative to their own manufactures, and for their unfailing courtesy so cheerfully extended, and also to Mr. Searle, of the London General Omnibus Co., for his aid and advice in the designing of the chain-driven gear box.

To go into all the merits of chain drives applicable for general industrial purposes is beyond the scope of this Paper; appended are a few illustrations, with a very short description relative to each.

THE DISCUSSION.

Mr. A. Cautley, in opening the discussion, said: I did not really come prepared to take part in this discussion, but there are one or two points which occurred to me while listening to the paper.

In reference to Fig. 30, it so happens that the other day my firm received information about some chain driven gearboxes which have been used in France for the past two years; there are about 10 sets, and they are being run satisfactorily on motor lorries. The chain drives are somewhat heavier than those illustrated in the paper, but this is quite justified by the fact that a motor lorry has more first and second speed work than a motor bus.

Adjustment.—Mr. Hill did not touch very deeply on the question of the provision of means of adjustment. He says the use of a jockey pulley is confined to one or two positions of the chain drive, and shows it in Fig. 44 applied to the back of an inverted tooth type chain. With the type of chain made by Hans Renold, Ltd., and by the Westinghouse Co., we cannot put a jockey on the back of the chain on account of the peculiar formation of the chain joints. We find, however, that for horizontal drives with the slack side of the chain at the bottom, the importance of adjustment is not great, as the chain will adjust itself until it is possible to take out a link, but in automobile work it is necessary to have adjustment for various reasons; it is also much better to have the chain encased, as its position exposes it to so much dirt, which is not the case with chains used for other purposes. This is of particular importance with the inverted tooth type of chain on account of its design.

Hunting tooth.—On page 318 of his paper Mr. Hill says provision should, when possible, be made for a "hunting" tooth on one of the wheels. I think it is probable that he means the same thing as we do, but we do not call it a "hunting" tooth. We use an odd number of teeth on the pinion in order to minimise the wear on the tooth face. If there are an even number of teeth on the pinion the same combination of links always comes into action on the same tooth, and if there are an odd number of teeth practically the effect of a hunting tooth on a spur gear drive is obtained, whether there are an even number of links in the chain or not. The only case where it is necessary to have an odd number of links in the chain is where the number of teeth in the small pinion can be divided evenly into the number of links in the chain, and this does not occur once in 100 drives. This odd number of links in the chain would provide a hunting tooth action on the chain with reference to the number of teeth in the wheel, while the odd number of teeth in the small pinion in an ordinary drive provides for the averaging of the wear on this small pinion.

In large wheels, having more than 30 teeth, the question of an odd number of teeth is of small importance on account of the number of teeth in engagement with the chain.

Slack side on top or bottom of chain.—Mr. Hill does not say whether it is best to use the tight or slack side of the chain on the top in a horizontal drive. This is a question for engineering experts. There is some controversy about the matter, and we prefer the slack side of the chain on the bottom in order to have the force of gravity to assist the centrifugal action in bringing the chain out of gear with the pinion.

Factor of safety.—I think Mr. Hill is somewhat optimistic with regard to the question of factor of safety; structural engineers in building work are a little shy of going below 10, and in bridge work far higher factors are used. Of course, I quite agree with Mr. Hill as to the necessity of low factors in special cases. A bearing pressure of 650 lb. per sq. in. is a good average, but we use considerably higher pressures than this with entire satisfaction. The Westinghouse Co. have no bearing area in the sense we have, and they therefore have a different proposition to deal with in designing their chain drives.

I do not know whether Mr. Hill has been in competition with helical gears, but neither the Westinghouse Co. nor Hans Renold, Ltd., can claim very much higher efficiency than the best gears of this class. This is a question which we as chain makers have to meet, and which we cannot get away from, though we are not tied down to centre distances as the helical gear makers are.

Mr. LANCHESTER: How much per cent. is the efficiency?

Mr. CAUTLEY: The helical gear makers claim 96 per cent. efficiency or more. This is obtained by a double helical gearing which takes up its own thrust. In *Engineering* * recently there was published an article on the Melville-Macalpine reduction gear, made by the Westinghouse Co., of Pittsburg, in which an efficiency of 98 per cent. was claimed for this gear when transmitting 6,000 horse power from a turbine to a shaft with a 5 to 1 reduction. This efficiency was maintained for some 30 hours without any increase of heat in the gearing. This, of course, was a special case.

I do not care to go into the question of Mr. Hill's high speed chain, *i.e.*, the Coventry Noiseless Chain, but I may say that we made one similar to it in 1900 with a single bush forced through a pair of links for the small pitches of chain where we found it impossible to manufacture the liner satisfactorily. We are making a round bush chain, which has single thick links of the same quality of material as the thin links previously manufactured, and we consider this to be a more satisfactory method than using two thin links.

End play.—The question of end play is a vital one on all chain drives, and though a chain may be run out of alinement as is sometimes the case with motor car drives, it is not wise to do so. In an electric motor where the end play is often a very rapid movement, this question becomes a serious one, and has to be provided for by cutting down the end play.

On high speed engines, with a proper sized flywheel the chain drive is all right, but with many, both steam and petrol engines, the flywheel is wholly inadequate from the point of view of the chain drive, and some special provision must be made to take up the shocks in the drive. It should be noted that a flywheel of ample size for a motor car would not necessarily be large enough to reduce the cyclic fluctuation sufficiently to make a chain drive thoroughly satisfactory.

Mr. Hill mentions the question of the allowable variation on a guaranteed length of chain; I shall be glad to know what stress such chains are subjected to when tested.

Mr. Hill mentions 800 ft. per minute as a reasonable speed for small roller chains, but for tachometer drives and certain other special cases we use speeds very much higher than this. We do not, however, pretend that for regular work the roller chain can be used for such high speeds as the "silent

* *Engineering*, December 3, 1909, p. 763.

chain." We are at present running a "silent chain" in one case for somewhat special work, driving from an 80 h.p. motor at a chain speed of 1,500 ft. per minute. In another case, that of a motor car drive on the Phœnix car, our chains are running at speeds which sometimes attain 2,000 ft. per minute, and I must say I am quite surprised at their absolute silence. I may add that the engine to countershaft chain on the car which I recently inspected, was certainly less noisy on its top speed than a bevel gear could possibly have been. The chain used in this case was of 1 in. pitch, with a width of $1\frac{1}{2}$ in.

Mr. H. W. ALLINGHAM: I have been in charge of the chain shop of the Westinghouse Co. for some time; before that I was with the Morse Chain Co., and before that with Hans Renold, and have tried nearly all the silent chain makers except the Coventry Chain Co.

I notice Mr. Hill mentions the inverted tooth type of chain as being suitable for a speed reduction of one to six. We make a practice of putting our standard speed reduction at 1 to 10, 13 teeth to 130 teeth with a single end engagement chain, of the type represented in Fig. 18. This type of chain is different from the one illustrated in Fig. 17, it has a different bearing surface on the wheel; it is also completely different from that of the Coventry chain; the angle of the tooth or the portion of the tooth cut out remains constant, and it has the advantage that you can use one cutter for all the teeth no matter how many teeth there are in the wheel, and however large the wheel is, the drive is still approximately a right angle one. The driving face of the tooth is very nearly at right angles to the tangent to the wheel periphery, whereas with the type of inverted tooth chain such as we make for ordinary transmission in which we get a larger bearing surface, I acknowledge that the form of tooth on the wheel gradually becomes more and more of a "V" as the chain wheel gets larger; this "V" shape of tooth forms one of the reasons why a large wheel cannot be used. With single ended chains, however, we have, for example, a chain running from a 12 tooth wheel to one of 154 teeth, a ratio of about 1 to 13, utilising a very high speed motor for running a slow speed machine in which variable speeds are necessary. In all ordinary drives where so great a speed reduction is not required the ordinary type of chain (the double end engagement chain) is undoubtedly the most satisfactory drive, and it is only in cases of extreme reduction that the single end engagement type should be used. The Westinghouse Co. were the first to put chains on omnibuses, and the single end chain was the only type then built. These chains gave a considerable amount of trouble, but on the introduction of the double end engagement type that trouble was halved; we got double the work out of the new type. This shows the advantage of the double end engagement type now universally used on all but exceptional drives.

In regard to the guiding grooves, Mr. Hill maintains that a larger bearing surface on the wheels is obtained by the use of outside flanged links. I think I am right in saying that the outside flanged links are as old a method of guiding chains as the flanged wheels, and that the original chain built in France by the Sebin Co., and called the Varietur chain, always had a flanged outside link. On actually figuring this out it will be found that the overall width of the chain is about the same as, if not greater than, that of the ordinary chain. In point of actual bearing surface I do not think there is much to choose between the two methods. I think it is more a question of cheapness of production than anything else, and it is quite obvious that so far as the sprockets are concerned, the wheel for the outside flanged type of chain is cheaper than the grooved chain wheel which has to be so much wider.

I should also like to say something about chain speeds, which I will authenticate with an acknowledgment of the source from which my information comes, namely, the General Electrical Co., of Schenectady. This company was running a chain of 2 in. width at 4,200 ft. per minute. Although Mr. Hans Renold himself has never seen a drive of that sort running, I believe Mr. Cautley has. Personally, I would not recommend speeds of that kind, nor should I care to be near a chain that was being driven at that speed, but I understand that it ran for five hours a day, and that it kept going for four months. Though it is not a commercial speed, it shows what can be done.

Fig. 43 gives an illustration of a heavy drive, by means of a chain made by the company with which I am connected. We have supplied seven sets of these, so that we have 3,500 h.p. being transmitted by chains running at a speed of 1,400 ft. per minute, which is a big drive running at a high speed.

I must say that I am not altogether favourable to the use of chains in automobile practice. Besides being in the chain business, I am also a motorist, and interested in pleasure cars, having had a number of them (22 to be exact) within the last eight years. I am a votary of the live axle drive rather than of the chain drive. I have experimented with our own chains and others, and my own impression is that a chain drive on a private motor car, which is most indifferently looked after as a rule, has a lower efficiency than the live axle drive. If you can get a chain encased, and adjusted exactly right, and kept clean, and the sprockets not allowed to wear too much, and everything else kept just right, a chain drive, with the differential bevel drive included, may have almost the same efficiency as a live axle drive, but personally, I have always felt that the efficiency of the chain drive when it is getting towards the end of its life is very low indeed. I think the private owner is losing more on the chain drive than he would on the live axle drive, especially as he cannot be made to look after the chains in the way he should do, and I am not at all surprised that live axles have very nearly superseded chains for use on pleasure cars. As far as commercial vehicles are concerned, I leave men with wider experience than myself to judge.

Mr. F. C. A. Coventry: I cannot claim to have had a really extensive experience with chain driven cars, or one that compares with that of other gentlemen in this room who are operating commercial vehicles. I have had fifteen chain driven cars during the past five years, but unfortunately they have not done quite so much mileage as they ought to have owing to reasons not connected with the chains. As far as my experience goes, I am not much in favour of chain drives, owing to their high maintenance cost. The cost of a set of chains for a heavy vehicle comes to, I think, from £15 to £18, and Mr. Hill says cases have been recorded where they have done 18,000 to 25,000 miles. The ordinary gear and pinion drive costs something like three guineas, and cases have been known where they have done as little as 25,000 miles, that is, where they are properly enclosed. They will, of course, do less if they are not enclosed, but it is an easy matter to do this. I think that chains could very possibly be made satisfactory if a really good gear case were to be designed, but no one seems to have solved this problem up to the present. The case should be made of some non-rattling material such as wood or leather, or some kind of paper composition, rubber or vulcanite; it should be easily detachable and reasonably cheap.

It does not seem to me impossible to get out such a gear case if the matter were gone into, and I am surprised that the chain makers themselves do not supply them. I do not know whether Mr. Hill has ever considered this question.

Another point is that the gear and pinion drive gives a higher reduction for the final drive than can be obtained with chains, and this enables all the shafts to be run at high speed, and so they can be kept light right up to the wheels.

A further point is that the chain makes the wheels very much more difficult to change. With a pinion drive the nut and washer can be taken off, the wheel comes off and another goes on, but with chains it is a complicated matter. For country road work it is impossible to keep chains up to a good condition. If a chain driven car has a run of twenty miles out and twenty miles back, it is necessary to stop on the road to oil it, clean it and look after it.

With regard to the chain driven gear-box, I have had a look at the design of one of these, and I do not think very much of it. It contains a number of chains in addition to all the parts present in an ordinary gear-box; these parts are much more expensive to make, much heavier, and necessitate the whole gear-box being of greater size. I take it that this is only being forced upon the companies by the police for the sake of silence.

If chains are to have a future for commercial work, the vehicle I should like to see designed would be one of very simple description with a single epicyclic gear, and a single chain drive which could be properly enclosed; this could be made about as cheaply as anything that could be designed.

Mr. F. SEARLE: I am afraid I cannot agree with Mr. Coventry so far as the gear drive is concerned. He might have found it satisfactory in country work, but in London we have in the neighbourhood of 400 gear driven buses, that is with a final drive of the rack and pinion type, and 400 with chain drive, and I really think the chain driven vehicle has proved itself to be more economical in working than the rack and pinion type.

With regard to the chain driven gear-box, Mr. Coventry is practically right. It was clearly forced upon us by the police. They have set up a standard, I was going to say of noise, but I will say of silence now, which is very difficult to meet. In the first place, I remember two years ago their test used to be out on Wimbledon Common up a hill of one in twenty-five with no load on the bus. To-day they give you a 2 ton 5 cwt. load of sand and two passengers to take up a hill of one in seventeen, and make you stop and restart, and you have got to do that without making any noise. I failed to fulfil these conditions with a gear driven box. It was then that we had the chain proposition brought before our notice, and we had to adopt something. Up to the present we have got four vehicles running with chain driven gear-boxes. I think they have accumulated now something like 10,000 to 12,000 miles between them, and nothing extraordinary has happened up to the present.

Although Mr. Hill has spoken about noiseless chains, I might tell you that in spite of these having been installed in the gear-box, the police only on Tuesday last refused to license three out of four buses by reason of the noise on second speed, and I think we shall have to go back to rope drives.

Colonel R. E. CROMPTON: I have been an admirer of the chain drive for road vehicles ever since Aveling introduced them into his traction engines in the year 1862. Aveling used block chains, and eventually built locomotives to run on rails using chain transmission, the engine being on the top of the boiler, and transmitting the power from the crankshaft by one chain passing round the pinion on the crankshaft, and pinions on the two axles, thus coupling them together. In spite of the difficulties in correctly manufacturing these early chains, they worked so satisfactorily that I never understood why Aveling did not carry the matter further. When I returned from service in India many years later, I found that the chain proposition had practically dropped. I next encountered it in the early days of the bicycle, and was one of the first users of the $\frac{1}{2}$ in. pitch single roller chains which were introduced by Mr. Garrard, a member of our Council. I was the introducer of very long cranks for bicycles, and I was found to be a very efficient tester of the early roller chains, as with my $9\frac{1}{2}$ in. cranks I could put abnormal stresses on to them. The great improvement of the roller chains of those early days was due to the advances made by Mr. Garrard himself, Mr. Hans Renold, and eventually by Mr. Hill. I noticed with surprise how long it took our French neighbours to appreciate the great advantage of single roller chains for driving automobiles. For a long time they used double roller chains with all the difficulties they entailed. Although we must admit that to-day is the day of the live axle, and that chain drives are being gradually abandoned for pleasure vehicles, I have watched this change with regret, and felt grave doubts as to whether it is justified. I believe it to be largely the result of fashion, and to be one of those so-called improvements which may not be after all the best for efficient working. I agree with Mr. Hill that many users of gear drives do not know how much that drive increases the wear of their pneumatic tyres, and I am quite certain they do not appreciate how much the same drive increases the wear of the roads owing to the increased unsprung weight on the back axles. At any rate, for commercial vehicles and for large pleasure vehicles, I still believe that from this point of view the chain drive is the best. The durability of chains properly protected from mud is extraordinary. On my 6 h.p. White steam car, I personally ran a central chain made for me by Hans Renold for a period of seven years, and I believe the mileage it covered was 60,000 miles. I returned the chain to Mr. Renold as it was not then fully worn out. This chain was unprotected, but it was centrally placed, and although it naturally got some dust it did not get any mud on to it. I believe that many of the single chains on the original Serpollet cars, although they were not quite centrally placed, were sufficiently distant from the road wheels to escape part of the mud bath, and wore well. I believe that the reason the chain got such a bad name was that in most cases it was neglected by private users, and certainly in the early days of the London omnibuses the chains were neglected by those responsible for their upkeep. They were placed so as to receive a stream of wet, gritty mud directed on to the interior surface, almost as if the designer had wilfully tried to wear them out by lubricating them with gritty material. I do not think it is necessary to have a complete gear case. Chains can be sufficiently protected by a simple deflector to prevent gritty matter being thrown on to their inner surfaces. I have done a good deal of designing in the direction of large commercial vehicles, especially tractors, and I still think it is far easier to design a satisfactory commercial vehicle having large wheels by using chain drive. I have tried all ideas of gearing, external wheels, and internal racks, but I have come back to the chain as the only means by which great flexibility of frame combined with facility for controlling what Mr. Lanchester calls the side-location of the load can be obtained. In my work as an electrical engineer where, on account of speed reduction from the motor to the shaft to be driven, high efficiency is imperative, Mr. Hill's figures as to the efficiency he has obtained with the inverted tooth chain are supremely interesting, for I suppose that it is realised that the old idea of a workshop full of shafting is rapidly disappearing, and that every day we see a larger percentage of the tools provided with separate motors each of which requires speed reduction with as little loss of power as possible. The chain drive question may even be of supreme importance for heavy power transmission for marine purposes; it is quite possible that there will be a large future for the employment of chains for reducing the speed of the propeller shaft from that of the turbine shaft, to improve the propeller efficiency. After listening to this paper, I ask all mechanical engineers whether it is not a pleasure to hear of such triumphs of mechanical skill as have been shown in the development of chain manufacture, and in the splendid efficiencies that have been brought before us to-night. No one can walk round Mr. Hill's or Mr. Renold's works without feeling that he is in the presence of extremely perfect methods of dealing with materials, and of producing perfect workmanship at extremely low cost.

Mr. C. R. GARRARD: In the first place, I may say that the statements with regard to the introduction of the $\frac{1}{2}$ in. pitch roller chain which have been made are not quite correct. I wish to disclaim the honour of being the inventor of that chain. I think it was Mr. F. J. Osmond who invented it.

Mr. Hill, in referring to rivets, says that the dead hard ends are rivetted over, and I should like to ask him how that is done. I should be afraid of tapping a piece of such brittle material. The old practice used to be rather interesting. We took a large ingot of steel about 3 in. square with a highly carbonised surface, and a low carbon interior. This would go through a rolling process in the wire mills until one end was of the right size for making rivets. The resulting rivet when shouldered to the proper section then had one part of it deeply hardened, while the other part had a very shallow skin, that is, it was hard where the wearing surface came, which is what we wanted. This may be made clearer by a sketch (Fig. 45).

Mr. Hill has scarcely brought out sufficiently the virtues of the roller chain. We used to put up with block chains in the early days; rollers were thought to be a little superfluous. I do not think it has been shown clearly enough where the advantage of the roller chain comes in. The roller generally is in the form of a sleeve, which comes into contact with the teeth of the chain wheels, and it is really a very small point of contact, in some conditions in fact, merely a line contact between the two surfaces. But inside the roller there is a length about equal to the diameter which gives a much larger area of surface contact, besides which the inner side of the roller has more chance of being clean than the other surface. That was one of the great virtues of the roller, which was thought by many to be a superfluous thing.

Regarding chain drives generally, I should choose this form for anything in which the drive is constant and positive, but in other cases where the drive is intermittent, as for instance in

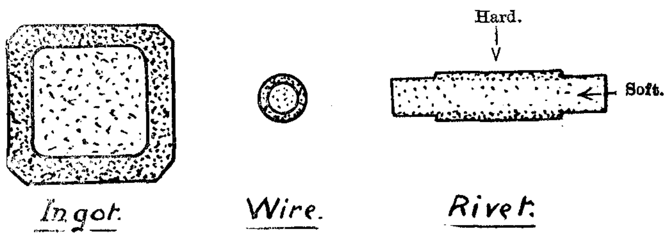


FIG. 45.

a single cylinder engine, I do not think the chain would behave at all well.

With regard to the Morse chain proposition, with the rocker chain, the wear would take place on the slack side, and not on the loaded side. The spring drive referred to was in use a long time ago. You will find it on the Gladiator tricycle, one of the first motor tricycles ever made, but we broke a few springs before we got it right. There is one point which has not been strongly enough impressed on designers, but which is very important in connection with the automobile; I speak from experience. I had great difficulty in getting designers to cut the chain wheels greater in pitch than the chains. This should certainly be done, and then the chain gradually comes more into pitch as it wears. The importance of this needs bringing to the notice of those designers who are interested in roller chains.

I should like to mention another point to which Mr. Hill has not, in his own interest, drawn sufficient attention. I have seen any number of breakages of chains and chain wheels due to the shape of the teeth. Some chain wheels have their teeth shaped in section as *a* (Fig. 46), others like *b* (Fig. 46), and the best kind as *c* (Fig. 46). We have here first a bad form, then a better, and lastly, the best.

Chains never break under drive, but only when they are slack, as when coming down hill, never when going up hill. I would impress on owners the great difference between the power of the foot brake and that of the engine. The foot brake to be of real use is always five or six times as powerful as the engine.

Mr. ARTHUR C. CLIFFORD: I want to ask Mr. Hill a question on the alinement of chains, especially those of the inverted tooth types with centre guide link. On page 325 of the paper he says that one of the advantages of the chain drive is that the wheels may be splayed, but to do that the pinion must of neces-

FIG. 46.

sity be out of line with the back ring. Is it more beneficial to aline on the top side or on the under side of the chain? I have had some difficulty in respect to alinement under such circumstances. Mr. Hill also makes a remark that the ratio should not be greater than $2\frac{1}{2}$ to 1. We are getting particularly good (and, I believe, record) results with a ratio of $3\frac{1}{2}$ to 1. I speak as a user.

Another question I want to raise is a commercial one. I have to consider this matter more from the commercial point of view than from a purely engineering standpoint. With the Coventry inverted tooth chain I see a rather serious commercial disadvantage by reason of the cost of repinning. In the case of the rocker chain, it is only necessary to drive in about two pins, rivet up, and the job is finished, but with the Coventry chain, not only have the pins and a lot of bushes to be drawn out, but new bushes and pins have to be fitted, and it strikes me as rather an expensive job. I should like to know if Mr. Hill could get over this "commercial" difficulty satisfactorily. Can he tell me also if there is any practical advantage in the pin and bush chain over the rocker? Personally, I have a prejudice against taking up anything not purely British, but I do not want to use the Coventry chain unless there is some advantage in it. It is important to motor bus people, of whom there are one or two here, and they would be glad of information on this subject.

Mr. J. Lyons Sampson: On page 327 of the paper, chains are mentioned as actuating the valve gear on the Knight engines which were tested by the R. A. C. under very severe conditions. I am interested, as I superintended that trial. It is stated that one of these chains lengthened by 3/64 in., the other by 1/16 in. Mr. Hill explains the difference (25 per cent.) by drawing attention to the fact that one was on a 38 h.p. engine, and the other on a 22 h.p. engine. The paper, however, stated that the chain that stretched least was on the larger engine. Mr. Hill might state if this is correct.

Mr. F. W. Lanchester: I think it would be of great interest if Mr. Hill could give us some further information as to the effect of a jockey pulley upon the durability of the chain, the best material for facing such pulleys with, and whether it is advisable to use any particular diameter in relation to the chain pitch. The question of facing the jockey pulley is of some importance owing to the extent to which the design may be simplified. If it is permissible to use a hard steel surface, a standard ball bearing may be fitted with the chain running direct on the exterior of the outer race. If a leather facing is expedient, such a simple device is of course out of the question.

Some information as to the actual dimensions of the chain driven gear-box to which Mr. Hill alludes would, I think, be of value; that is to say, the type and width of chain; the particulars of the gear wheels and of the power transmitted. This type of gear-box is a comparatively new development which may possibly have an important place in the future of the heavy vehicle.

In view of Mr. Hill's remarks on the importance of accurate alinement, it would be interesting to hear something from him as to the suitability of the chains in question as cross chains for aeronautical work; the alinement in such a cross chain drive is necessarily defective.

I think we should appreciate it if Mr. Hill, in the final printing of his paper, would express the efficiencies that he has given us in the form of graphs, so arranging the diagrams that the position may be seen at a glance.

Mr. A. S. Hill, in replying to the discussion, said: I particularly wish to say how much I appreciate the presence of representatives of Messrs. Hans Renold, and the Westinghouse Brake Co., who took the trouble to come and hear the paper read, and entered into the discussion in so broad a spirit. Realising that I am a younger member of the trade, I fully appreciate the compliment they have paid me, and in replying to the discussion I shall endeavour to do so as fully as possible.

Mr. Cautley, who represents the Hans Renold Co., told us that the chain driven gear-box has been in use in France for two years or more. I was unaware of this, but am glad to hear that they have proved so satisfactory. If rightly designed, and proportioned, I have every reason to believe that they will stand up to the most severe conditions to be found in commercial vehicle drives.

Whilst agreeing with Mr. Cautley regarding the automatic adjustment of chains by their sag, it is apparent that this is possible only with comparatively long drives; under such conditions, I think it is advisable to have the slack side of the chain at the bottom, as this tends to prevent the inner sides of the chain coming in contact when the maximum elongation permissible through wear has taken place; this maximum is, of course, equal to the pitch.

The "hunting" tooth mentioned in my paper, and the relation between the number of teeth in the wheels, and the number of pitches in the chain, as suggested by Mr. Cautley, are virtually the same, and ensure an even distribution of wear over the whole drive.

Mr. Cautley thought my factors of safety too light, but that is one of those points upon which experts must agree to differ.

I was glad to know that he thought that 650 lb. per sq. in. bearing pressure was moderate, and it is not too much to assume that the relation between the bearing pressure and the ultimate breaking strain of correctly designed and proportioned chains is as generous.

I have not had an opportunity of demonstrating the efficiency of chain drives at very short centres, but feel sure that, with wheels of normal ratios, and with not too small a number of teeth, equally high efficiencies can be expected.

Mr. Cautley referred to the question of making "noiseless" chains from single plates, rather than with double plates of comparatively thin section mechanically fixed together. The reason why I prefer two plates joined together by a single hardened bush is because it is possible by this means to obtain a harder material, and therefore one that will have a higher tensile strength than would be obtained from a single link of actually thicker material in one piece.

It is true that on high speed engines, and often on low speed engines too, flywheels of insufficient capacity are fitted, but while such conditions suggest the advisability of a spring drive, do not the chains themselves provide a flexibility not obtained with other forms of gear drives?

In reply to Mr. Cautley's question, three-quarters of the breaking load of a chain is the test which is put upon cycle chains to give the results I gave earlier in my paper.

It is very interesting to know that Mr. Cautley has obtained satisfactory results on an automobile drive with a chain speed of 2,000 ft. per minute. I am not surprised, as the particular drive he mentions is one where the driving chains are in a position where mud is not being splashed on them, which, as Colonel Crompton has pointed out, doubtless has a great deal to do with the good results obtained at such high speed in similar cases.

Mr. Allingham spoke of the single end type of "Inverted Tooth Chain" by which smaller diameter wheels can be used with success, and in his later remarks he expressed the opinion that the double ended link, made by other chain manufacturers also, gave a more efficient chain. This is distinctly interesting, and a comparison of efficiencies from tests would undoubtedly be instructive.

I have not claimed that the outside member for guiding chains is new, but there are some old ideas which it is quite wise to adopt, when they have satisfactorily stood the test of time. Neither do I claim, in my paper, that the width of chains fitted with the outside guide plates is decreased, or even maintained, but that, for a given available tooth width, the wearing area of the chain joint is increased when such outside guide plates are used.

I agree with Mr. Allingham that when the overall width of chain is not of particular importance, the outside guide chain is preferable, if only because the wheels for that type of chain are somewhat easier to produce.

Coming to the American drive at 4,200 ft. per minute, I have no doubt that such speeds have been accomplished, but when in operation, I think that distance lends enchantment. This example of high speed driving, however, cannot fail to be of interest to engineers generally, and especially to those who are considering the transmission of power for aviation purposes. While such high speed drives cannot last long, they show to what extent excessive chain speeds can be used if really necessary.

It is rather interesting to have Mr. Allingham telling us he prefers live axle cars to those with chain drives, but we have to put that against the statement made by Colonel Crompton, who said, in effect, that "no vehicle is complete or perfect without chains." He was referring to the heavy class of motor vehicles, whereas Mr. Allingham was referring to pleasure vehicles.

The high efficiency of chain drives, however, is well maintained even in worn wheels, and it is evident that the efficiency of bevel wheels of approximately equal size in the gear-box, running at a fair speed, and isolated from road shocks, must be higher than that of the slow speed and high reduction bevels used in live axles.

In regard to Mr. Coventry's remarks, I am under the impression that his costs for chains and chain wheels are certainly on the high side. It would be of interest to know whether he referred to the cost of two chains and wheels, or simply to that of one new chain and possibly a new pinion.

On the question of Mr. Coventry's experience on country roads, I personally think that if I were going to use a commercial vehicle consistently over such roads, and the chains were in a bad position, I should carry a grease pot and daub some on the inside of the chains at every suitable opportunity.

Of course, the chain driven gear-box necessitates a slightly larger box than is generally used on present-day vehicles, and, on account of this, is fitted more particularly on commercial vehicles and motor buses. Its application to pleasure motor vehicles has the serious consideration of eminent motor engineers, who desire the minimum of noise and the highest efficiency in the gear-box from the first moment of running.

Mr. Coventry said he rather favoured the single chain properly enclosed, and I certainly think there is a very big future for a small car with a single central chain drive properly protected from mud and dust, although it is, as Colonel Crompton has pointed out, a singular fact that the single chain drive keeps itself clean without being encased. The short life of the double chain drive is practically due to the fact that a stream of mud is continually directed on to the inner faces of the chains.

Mr. Searle's chief trouble seemed to be rather with the police than with the chain makers. It was interesting to note how he disagreed with Mr. Coventry in finding the chain drive cheaper than the live axle, from very extensive experience.

In Colonel Crompton we have an admirer of chain drives generally. It was interesting to hear him say that he was recognised as a champion breaker of chains in the early days of the $\frac{1}{2}$ in. pitch roller chains on bicycles, yet he loved them so well that he persuaded Hans Renold to adopt the manufacture of them, and Hans Renold, I believe, made them partly as the outcome of Colonel Crompton's experiments and experience.

Colonel Crompton went so far as to say that no modern factory should have shafting in it—I cannot go so far as that. It depends absolutely on the work to be performed. With a steady constant load, shafting would be preferable.

It is true that Mr. Osmond was the first designer of the $\frac{1}{2}$ in. pitch chain, but I was under the impression that to Mr. Garrard was due the honour of being the first to manufacture it.

Mr. Garrard asked about the rivets with dead hard ends. What I said was, that these were rivetted over by means of cushion hammers giving a series of light blows rather than one heavy blow. Heavy blows falling on this hardened material would, of course, break it, but by repeating a series of comparatively light taps, even a hard material will eventually burr itself over.

Mr. Garrard is no longer in the chain business, or he would have known that his old practice had been done away with on account of the difficulty of obtaining a uniform degree of hardness throughout the material. We found the material hard in places and not in others, the hardness running in streaks right through to the centre.

It is perfectly true that spring drive wheels are old, and it is also true that trouble was experienced with the springs in the early days of their manufacture. Springs of to-day have not remained as they were a few years ago, and we are now able to design and manufacture springs that will carry practically any required load.

In regard to making chain wheels greater in pitch than the chain, that is a matter which the manufacturers of roller chains at once brought to the notice of actual users, now a number of years ago; especially have I been an advocate of that principle in its extreme. To-day, I believe, it is generally acknowledged that a greater allowance should be made in the pitch of the chain wheel, but I do not think it is advisable to do this to

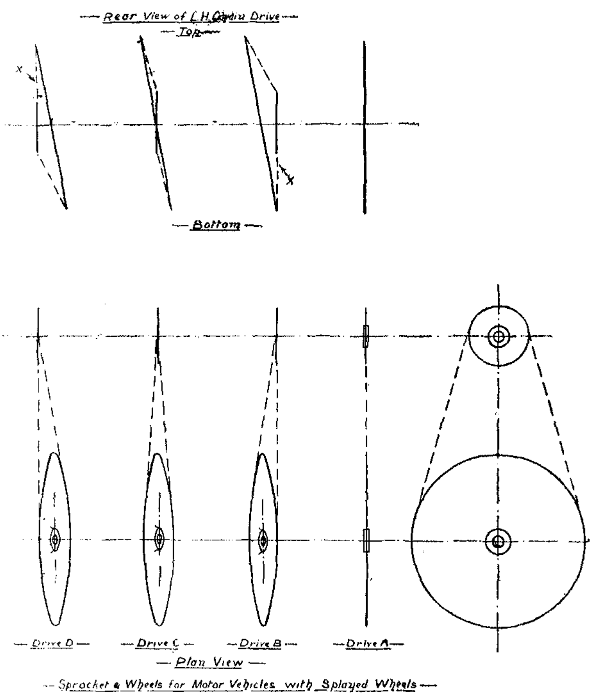


FIG. 47.

the extent that was originally recommended by some of the chain manufacturers.

In regard to the form of teeth mentioned by Mr. Garrard, I would refer him to Fig. 26, which shows that I recommend the same type of tooth as Mr. Garrard shows in his sketch, Fig. 46, as being the best.

On the question of alinement of chains asked by Mr. Clifford, I would refer him to Fig. 47.

Drive *A* represents the ideal drive, both wheels being strictly in line. When splaying is necessary, it is essential to have the tight side of the chain in alinement, as in drives *B* and *D* where the tight side is respectively at the bottom and top. In such cases, however, the drive should always be in a constant direction, and should not be reversed. When both wheels are alternatively driving and driven, the wheels should be relatively as shown in drive *C*. It should be noted that the twisting movement of the chain is practically the same in drives *B*, *C* and *D*, and only depends on the angle of splay. With flexible chains, such as the "Noiseless" type, this twisting movement is not of great importance, but the entering and leaving angle of the chain and teeth should be approximately of the same magnitude on all reversible drives, such as the road wheel drives of automobiles and buses, to overcome the tendency of the chains to mount the sides of the teeth.

Mr. Clifford spoke of the expense of re-pinning and re-bushing worn chains; while this may have been a consideration in the early days of chain drives, it is not nearly of such importance with chains made under present conditions. Especially is this so with the "Inverted" tooth type of chain where the wear on the link faces is in excess of that on the joint pins. Should it be necessary, however, to replace a pin in "the Coventry" "Noiseless" chain, it can easily be pushed out when one washer has been removed from its end.

I am not going to enter into the question of the advantage of the plain joint chain over that of the rocker, or *vice versâ*. That is one of the points which should not be explained by a maker who adopts the one principle in preference to that adopted by other makers. I have adopted the plain bearing chain chiefly on account of simplicity.

In reply to Mr. Lyons Sampson, I am obliged to him for drawing my attention to an obvious slip which has been corrected in the text.

In reply to Mr. Lanchester, I regret that I have not yet been able to compile the efficiency curves.

Regarding the fitting of standard ball journal bearings as jockey pulleys, suggested by Mr. Lanchester, this will be possible only under certain conditions. If the sag of the chain is slight, the contact between the chain and jockey pulley is practically a succession of points, and the pressure is small. The friction between these points, and the outside of a ball journal bearing, would be very small, and it is doubtful if the outer ring of the bearing would revolve at all. With a greater amount of sag, and therefore an increase in the arc of contact, ball bearings as jockey pulleys should give quite satisfactory results.

When jockey pulleys are fitted the side motion of the chain must either be limited by guides, independent of the pulley, or by the jockey pulley itself. In the latter case flanges may be fitted to the sides, or the pulley may take the form of a sprocket wheel.

With flat link chains, including the "Inverted tooth" type, where the centres are short, and consequently side motion of the chain practically non-existent, jockey pulleys may have a flat rim covered with leather or some similar material.

Regarding chain driven gear-boxes used on buses and lorries, the centres of the shafts vary from 6 to 8 inches, and the pitch of the chain used is generally $\frac{3}{4}$ in. To obtain the minimum of excess of chain on certain ratios of wheels, it is sometimes found necessary to fit the $\frac{5}{8}$ in. pitch in conjunction with the $\frac{3}{4}$ in. pitch on one of the drives in the box. The widths of chain used are adjusted to the various loads and speeds of the several drives. As far as cross driven chains are concerned, practically any of the modern types of chains I have named can be crossed, provided sufficiently long centres can be obtained.

The link type of chain, however, is more readily reversible, and at shorter centres than the roller or block type, on account of the sectional bearing of the links on the rivet, and the reversible chain, Fig. 19, Plate XXIX., which is somewhat more loosely assembled than the others, permits of being crossed at comparatively close centres.

The PRESIDENT: It is our business now to thank Mr. Hill for his paper. We have had a paper which has shown itself to be interesting by having produced such a very interesting discussion. We have had facts brought out which are new to some of us. I am not an expert on the subject, and many of the facts are quite new and interesting to me.

The high efficiencies have certainly surprised me. I did not know that efficiencies of anything like 98·5 per cent. had been reached. I remember the President of the Institution of Mechanical Engineers saying many years ago that he had actually measured the efficiency of a worm drive combined with a screw which was used for a certain purpose, and that he found it to be 3 per cent. That was on a 100 ton testing arrangement, and with a raw unfinished worm wheel 97 per cent. was lost in transmission. To-day we have the case reversed, we have now an efficiency of 97 per cent. and a loss of 3 per cent., and as Colonel Crompton has said, it is owing to the beautiful way in which machinery has been adapted to its requirements.

Mr. Hill has taken a line so very desirable in a paper of this kind, for by reading the paper we could certainly not tell that he had anything to do with one type of chain more than any other type. The result is that Mr. Hill's rivals have been able to take part in the discussion in a friendly way, and have given us much interesting information.

I ask all those present to join with me in according to Mr. Hill a very hearty vote of thanks for such a valuable contribution to our proceedings.

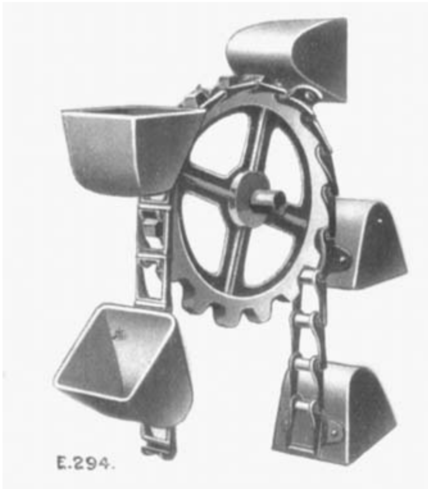


Fig. 1.—Bagshaw's Detachable Iron Chain (Ewarts Type).

Fig. 2.—Coventry Stud Chain.

Fig. 3.—Coventry Block Chain.

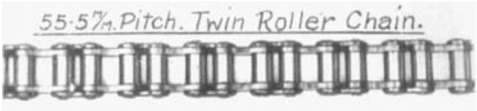


FIG. 4.—Coventry Twin Roller Chain.

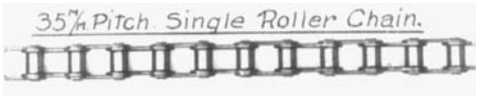


FIG. 5.—Coventry Roller Chain.

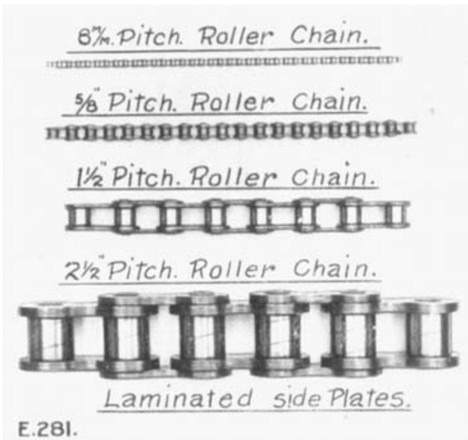


FIG. 6.—Coventry Roller Chains (from 8 m/m Pitch to 2½" P.).

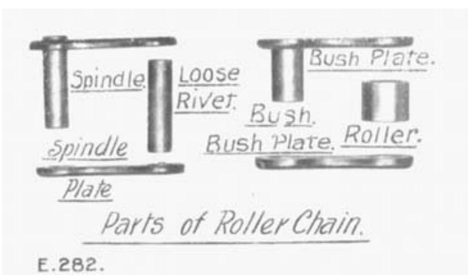


FIG. 7.—Parts for Coventry Roller Chains.

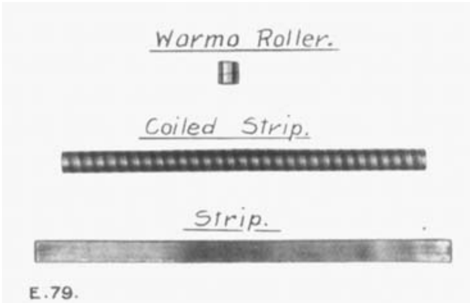


FIG. 8.—Wormo Roller for Coventry Roller Chain.

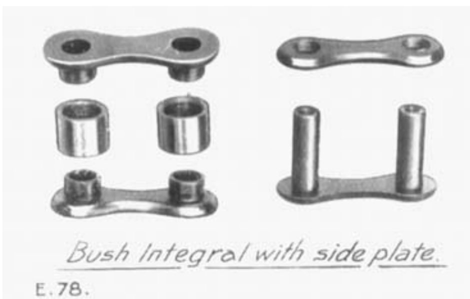


FIG. 9.—Coventry Roller Chain.

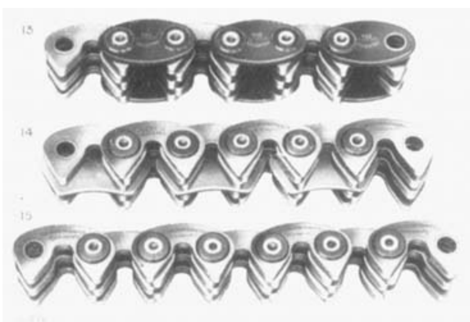


FIG. 10.—Three Types of Coventry Noiseless Drive Chains.

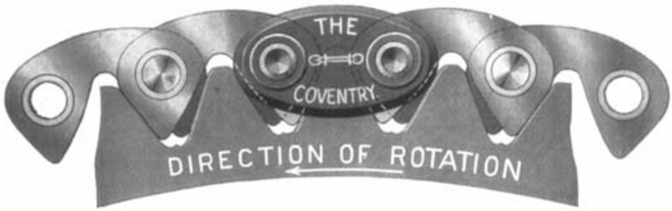


FIG. 11.—The Coventry Noiseless Drive Chain.

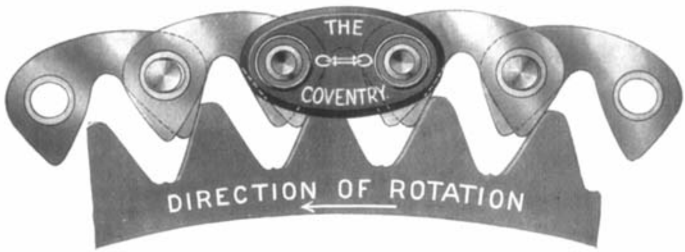


FIG. 12.

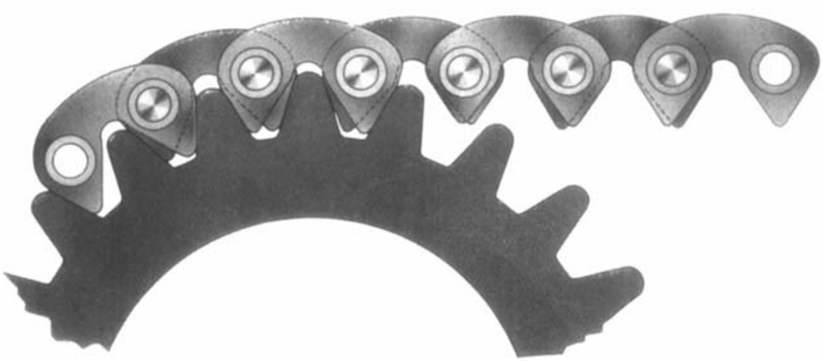


FIG. 13.

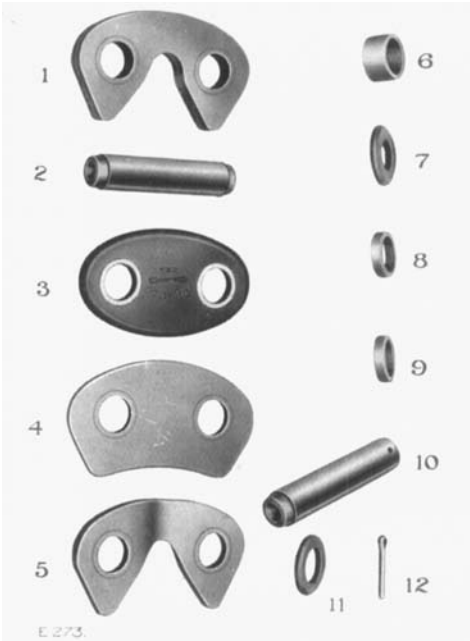
(1) Link comprising two Plates held together by Hardened Steel Bushes.

(2) Hardened Steel Rivet (varies in length with combination).

(3) Outside Guide Plate with Hardened Steel Bushes.

(4) Central Guide Plate with Hardened Steel Bushes.

(5) Cranked Link with Hardened Steel Bushes (only used with odd number of Links).



(6) Bush for Chain Link.

(7) Washer for Rivets.

(8) Bush for Outside Guide Plates.

(9) Bush for Central Guide Plate.

(10) Connecting Rivet.

(11) & (12) Washer and Cotter for Connecting Rivet.

Fig. 14.—Parts of Coventry Noiseless Drive Chain.

Fig. 15.

FIG. 16.—Renold's Noiseless Drive Chain.

FIG. 17.—Westinghouse-Morse Standard Double-End Chain.

FIG. 18.—Westinghouse-Morse Noiseless Drive Chain Link, showing Seat and Rocker Pins.

FIG. 19.—The Coventry High-speed Reversible Driving Chain.

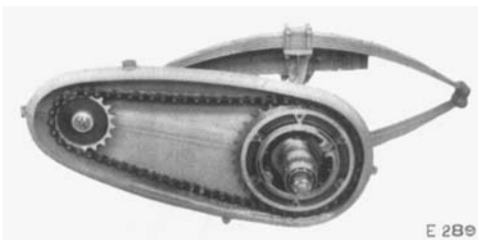


FIG. 28.—Roller Chains as applied to Automobiles, running in an Oilbath Gearcase.

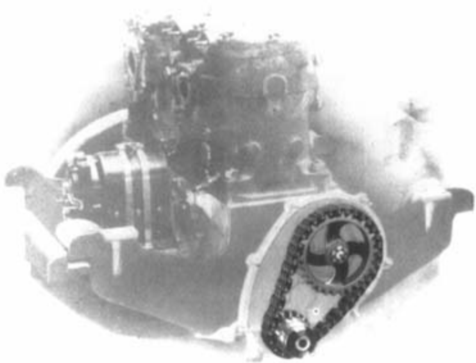


FIG. 29.—Knight-Daimler Petrol Engine. Mainshaft connected to the Eccentric Shaft operating the Internal Sleeve Valves by a Noiseless Drive Chain.

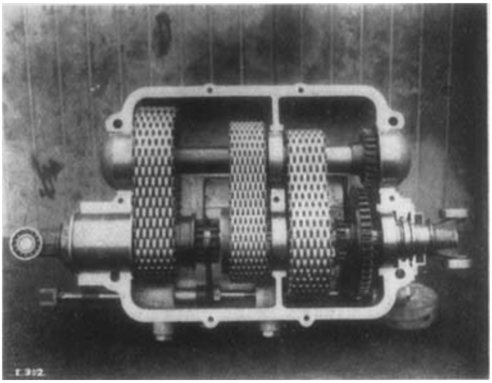


Fig. 30.—Gearbox fitted with Noiseless Drive Chains.

Fig. 31.—Motor Cycle Magneto Drive (Roller Chain).

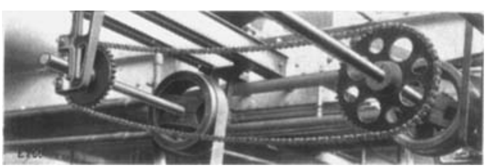


Fig. 32.—Shafting to Shafting by Roller Chain.

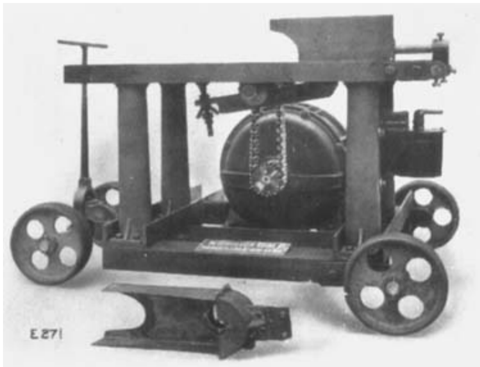


FIG. 33.—Portable Saw-Bench connected to Motor by Noiseless Drive Chain.

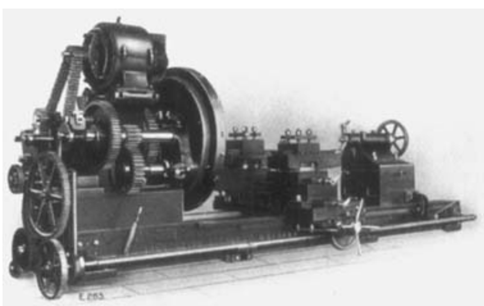


FIG. 34.—Motor connected directly to Lathe by Noiseless Drive Chain.

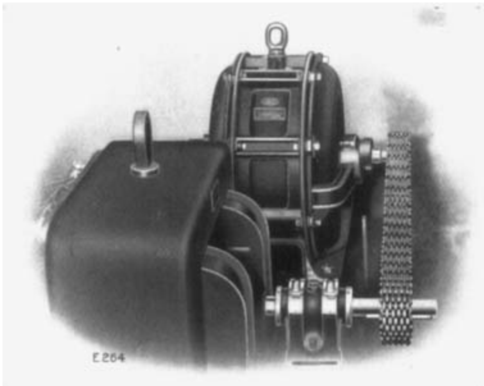


FIG. 35.—Motor Generating Set connected up with Noiseless Drive Chain.

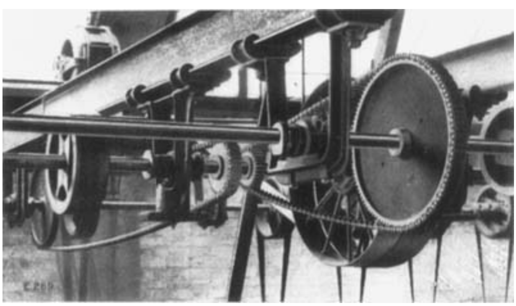


FIG. 36.—Shafting to Shafting by Noiseless Drive Chain.

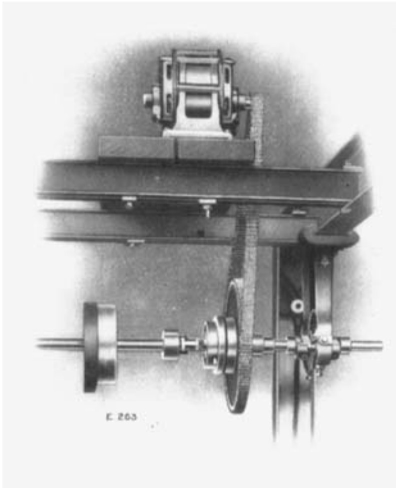


FIG. 37.—Motor connected to Line Shafting by Noiseless Drive Chain.

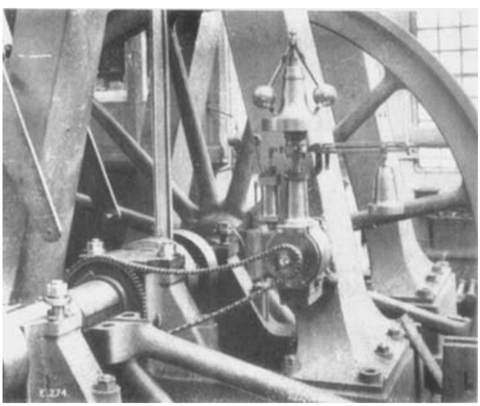


FIG. 38.—Governor connected to 214 I.H.P. Triple Expansion Engine by Noiseless Drive Chain. Speed of Engine, 23 R.P.M.; Speed of Governor, 161 R.P.M.

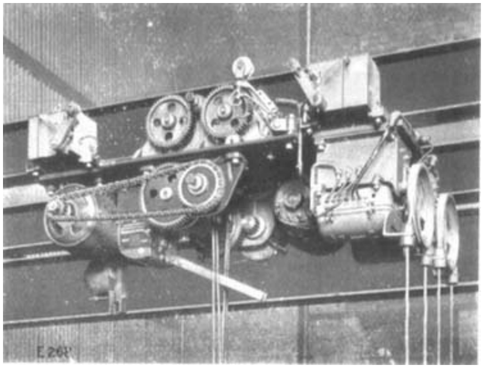


Fig. 39.—Noiseless Drive Chain fitted to Electric Crane.

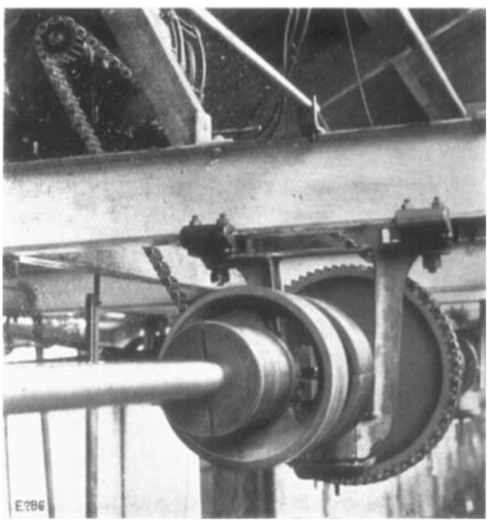


Fig. 40.—Motor connected to Line Shafting by Noiseless Drive Chain.

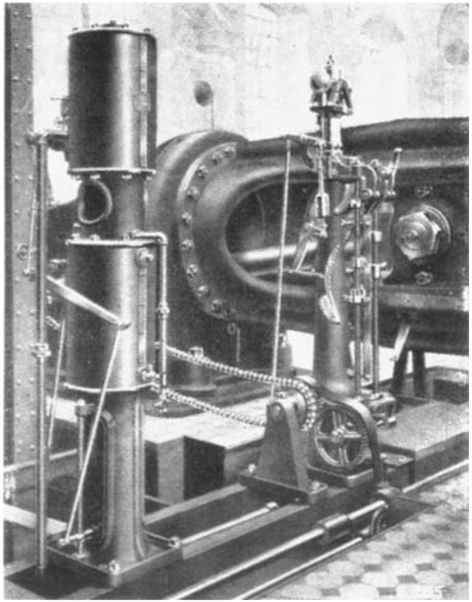


FIG. 41.—Standard Whitmore Brake Engine and Overwinder connected to a Corliss Compound Winding Engine by Roller Chain.

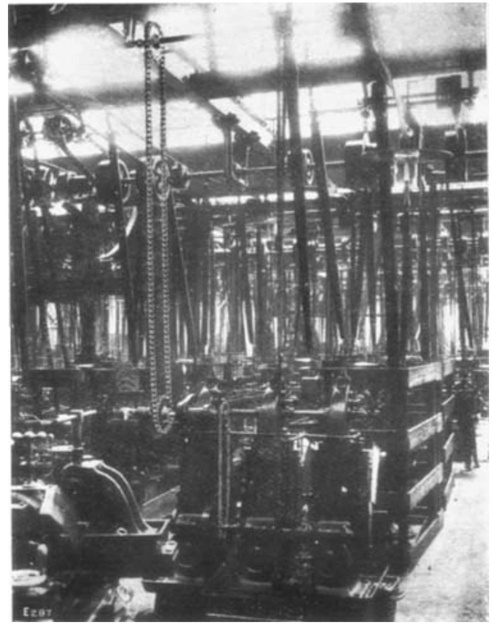


FIG. 42.—Three-Spindle Drill connected to Overhead Shafting by Roller Chain.

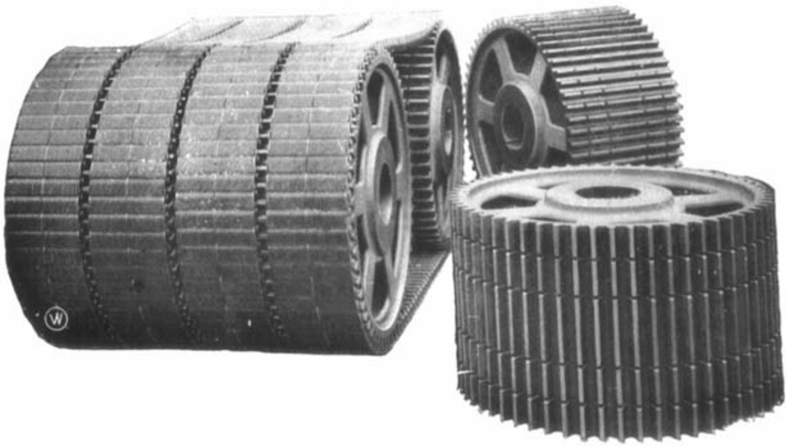


FIG. 43.—Three 500 H.P. Westinghouse-Morse Silent Rocker-Joint Chain Drives. Wheels, 59 teeth; Diameter, 37·8 in.; Two Chains 2 in. Pitch, 10 in. wide per Drive.

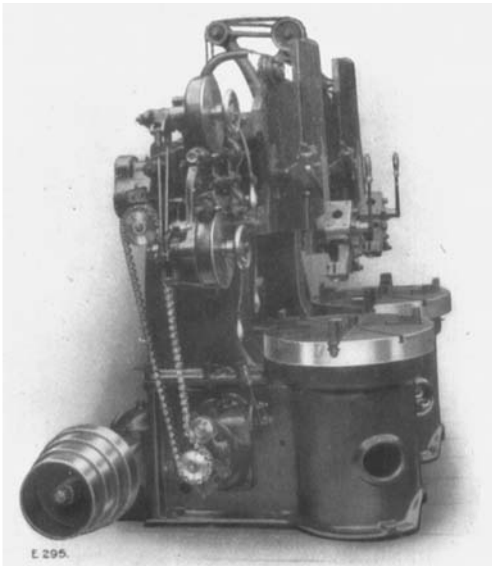


FIG. 44.—36 in. Duplex Table Type of Vertical Boring and Turning Mill.

A Noiseless Drive Chain is used to transmit the feed motion from the lower to the upper portion of the Mill. The rates of feed are changed by the lever on the front of the lower feed box, three rates being obtained by this means. The upper and lower chain gears are interchangeable, and of such numbers of teeth as will give an additional set of three rates when reversed.

The slack of the chain is taken by an adjustable idler, and the whole is enclosed in a substantial guard (removed to show the chain).