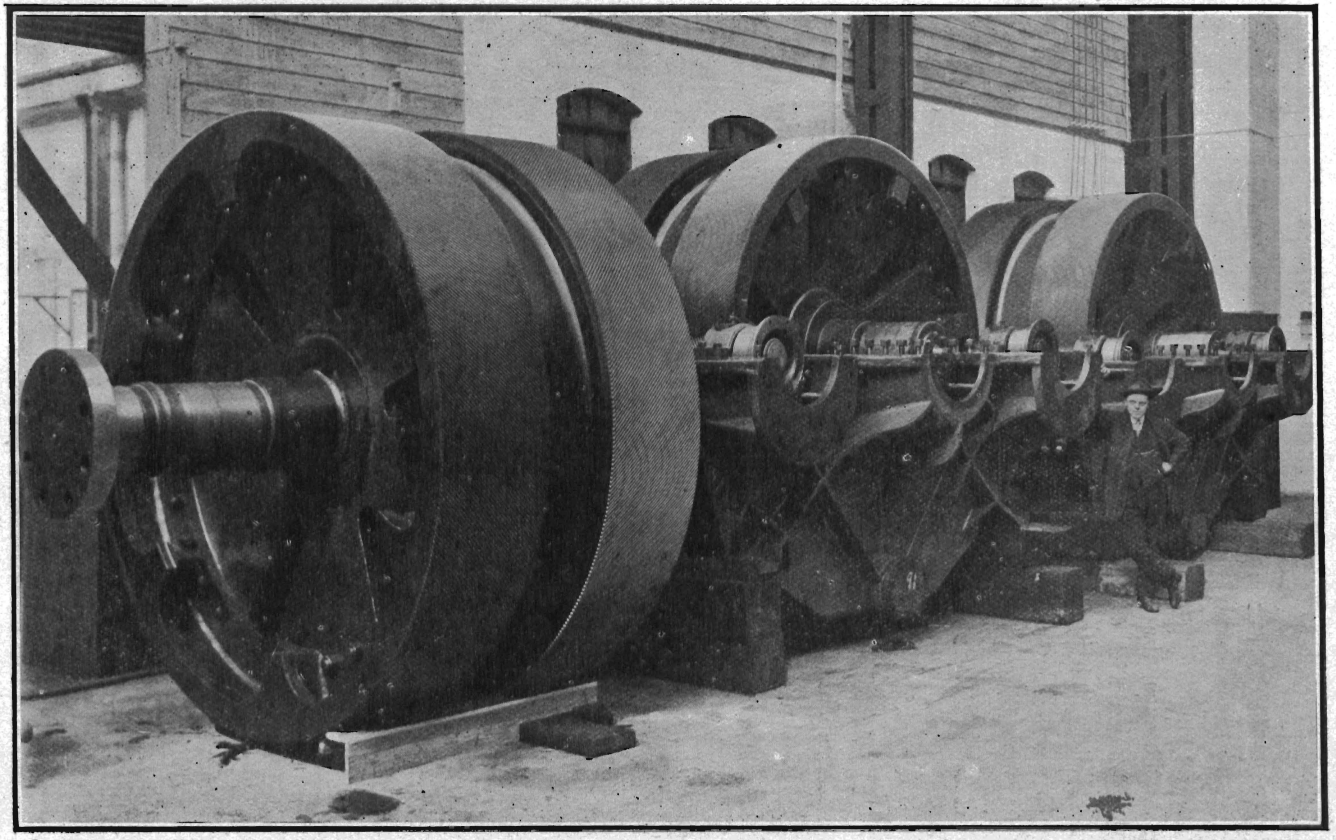

Fig 3.

are made of nickel steel, and the gear wheels are cut from a medium high carbon steel, generally in the form of a ring mounted on a cast centre, as shown on slides, and arranged with a bearing in the centre of the helix (Figs. 2 and 3).

ELECTRICAL.

In my introduction I first referred to turbo-electrical plant, and endeavoured to show under what disadvantages the D.C. plant particularly worked.

In the case of direct coupled turbo-alternators the revolving electrical parts can be made very strong mechanically, on account of their simple construction and low voltage, all electrical parts being well supported. The over-all efficiency being high, there is not much possibility of the geared turbo-alternator being adopted, unless it were possible to increase electrical efficiencies by several per cent. Knowing that only 1½ per cent. is lost in the reduction gear, it will be seen that it would then be possible that the geared machine would be more economical.

Against the increase in over-all efficiency is to be put the cost of gearing; but in the geared machine the turbine would be much smaller and less expensive, and so probably cheaper as a whole.

A very different state of affairs presents itself, however, in the case of turbine D.C. electrical machinery.

The demand is as real as ever it was for large D.C. plants, but the impossibility of constructing them in large sizes when no limit existed for turbo-alternators has, I think, made it appear that the demand for large D.C. plants does not exist.

Taking our own city, I think the metropolitan area—or that in close proximity to the power stations as in this case—could be more economically served both in traction and lighting by large D.C. generators; and, from all appearances, the large D.C. plant will considerably alter our present ideas, which are now naturally bound up with the alternating current plant.

The direct coupled D.C. turbine plants laboured under many great difficulties, and are now a thing of the past, and many Engineers will not, I fear, give them the honours of the dead.

The difficulty was to make the armature strong enough to withstand the centrifugal stresses, the chief trouble being with the armature end connections and the radial leads to the commutator.

Many attempts have been made to design these high-speed armatures with standard sunk windings, but none, to my knowledge, has been successful, and the wire-wound and semi-sunk designs were the most successful.

The trouble experienced in running these direct coupled D.C. sets is that of commutation and the heating of the commutator and brushes due to the high peripheral speed. Special carbon brushes were introduced some years ago, and assisted very considerably; but unless the brushes and commutator received very careful attention trouble resulted, generally of a very serious nature.

Again, the difficulties of keeping such an armature clean with the great air suction necessary to get the essential amount of air through an armature with a comparatively small amount of copper and iron was a most serious matter, necessitating frequent shutting down of the plant; and, all considered, one had longings for the slow-speed dynamo.

With the introduction of the geared turbine, it is now possible to combine the advantages of the high-speed economical turbine and the slow-speed reliable dynamo of large power, and such sets are in successful operation, having capacities which, a few years ago, one considered out of the question for D.C. machines. The demand for this D.C. type if machine proves, I think, my previous statement of the real need for such plant.

A well-designed low-speed dynamo is capable of the continuous running of an alternator, and these geared D.C. plants are in this respect equal to turbo-alternators.

The direct coupled turbo dynamo was inefficient compared with the slow-speed dynamo. This difference in efficiency is now saved with only a sacrifice of $1\frac{1}{2}$ per cent. in the gear-box, and the turbine speed being selected without consideration of the dynamo to be driven, the complete geared machine results in a very economical combination.

The simplicity of the geared turbo-generator—consisting of turbine, gear-box, dynamo and simple cheap switchgear—compared to the alternative scheme of turbo-alternator, rotary converter, and relatively speaking, expensive, complicated, paralleling switchgear, is greatly in favour of the geared machine.

Again, always assuming that a D.C. supply is required, the geared machine is less expensive than the turbo-alternator rotary converter combination, when the whole outfit from stop valve to D.C. terminals is taken into consideration.

Where alternating current supply is not suitable there are two alternatives: a turbo-alternator-rotary-converter can be used, or a direct current generator driven through gearing. It may be of interest to consider these two alternatives at some length.

Taking first the alternator-rotary combination:—

In this system it is the usual practice nowadays to permanently connect the A.C. side of the rotary to the alternator and to start the two machines up together. In order that this may be accomplished, it is necessary that the alternator should begin to generate as soon as it has begun to turn; in other words, that the rotor should be magnetised at the start. This means that the field of the alternator must be separately excited from some outside

D.C. source. As soon as the machines are up to speed the alternator can be changed over to self-excitation. There can be no doubt that this method of starting up has its disadvantages.

Since the relation between the slip ring and commutator voltages on a rotary is a fixed ratio, it follows that in this arrangement the alternator must be of comparatively low voltage, which involves a large amount of copper in the stator.

Alternators for use on this system are usually wound for six phases to suit the rotary. Since, as has been shown, the higher the speed of the turbine the more efficient it becomes, a 50-cycle rotary is essential in the system, as by its use the alternator can be run at 3,000 r.p.m. It is generally claimed now that a 50-cycle rotary is satisfactory in operation, but at the same time a 25-cycle rotary is to be preferred whenever possible, as it is at that frequency that the operation of the rotary is best. As we have seen, 25-cycle rotaries are inapplicable in this system. Another point which has to be considered is the liability of a rotary to reverse its polarity when starting—this is an obvious disadvantage.

With the geared D.C. generator none of these points have to be considered. The machine can be started up and paralleled with the other machines in the minimum of time. The turbine can be run at whatever speed is required by the designer to obtain the maximum efficiency. Commutation troubles such as are experienced with 50-cycle rotaries are eliminated. The voltage variation may be made as wide as desired, and the whole plant is simplified. The efficiency of the plant is also increased.

Consider the case of a 1,000 k.w. plant. Neglecting for a moment the fact that the geared turbine will be more efficient, owing to its higher speed, than the direct coupled machine—the gear efficiency being 98.5 per cent. and the full-load efficiency of the slow-speed D.C. generator 94 per cent.—we have a combined efficiency of 92.5 per cent. between the turbine coupling and the generator terminals.

On the other hand, taking the efficiency of the alternator at full-load as 92 per cent., and that of the rotary at full-load as 95 per cent., we have the efficiency of the combination between the turbine coupling and the converter terminals as 87.5 per cent., being 5 per cent. less than the geared arrangement, when considering the electrical portion only.

It may here be remarked that no account has been taken of the loss in the connecting cables between alternator and rotary, which, with low voltages and large outputs, may be quite considerable, unless the length of the cables be very short.

At ¾ and ½ loads the difference in favour of the geared proposal is much more marked; in fact, at ½ load it rises to as much as 9.5 per cent. The difference in steam consumptions in favour of the geared arrangement is dealt with later on.

One reason for the low efficiencies of the alternator in these combinations is due to the comparatively large copper losses in the stator windings, since the currents are heavy, owing to the low voltages used.

Numerous other points, small perhaps in themselves, but collectively important, might be brought out against the alternator—rotary combination—such as multiplicity of spares, larger amount of attention and cleaning required, two commutators to attend to—for even turbo-exciter commutators are not always an unmixed blessing—but enough has been said to show that the geared turbo-generator has certainly many points in its favour when compared with its rival, from an electrical point of view alone (Fig. 4).

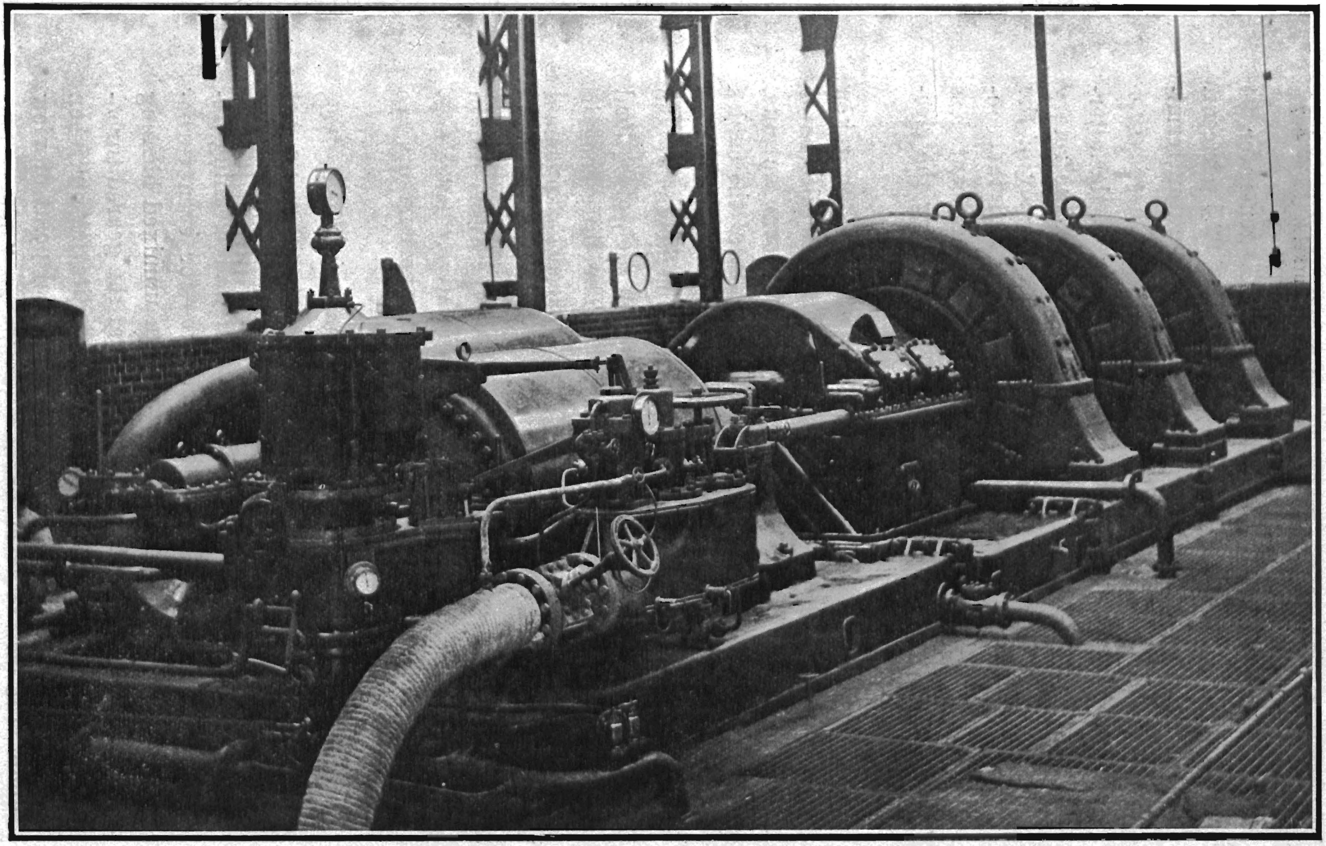

Fig. 4.

In addition to the electrical saving of 5 per cent. at full-load, and 9.5 per cent. at half-load, there is the additional saving at the steam end of the geared machine on account of a higher turbine speed being used than that synchronous to the alternator, namely, 3,000 r.p.m.

A geared turbo-generator of 1,000 k.ws. runs at about 4,000 r.p.m., and this difference in speed and higher coefficient design, combined with the superior over-all electrical efficiency of the geared plant, accounts for a total difference in favour of the geared combination of about 7 per cent. at full-load and a larger percentage at half-load.

At present it appears as if 1,500/2,000 k.w. is about the limiting capacity for single armatures.

In two systems, each of 1,000 k.w., the saving in space in favour of the geared turbo-generator amounts to about $33\frac{1}{3}$ per cent., which alone is a very important item in favour of the geared machine.

An interesting plant is at present being constructed for South Africa. From this station, A.C. and D.C. is required, so a combination plant was decided upon, the turbine driving the 1,500 k.w. alternator direct, and by an extension of the alternator shaft, the same turbine drives a 1,000 k.w dynamo through 10:1 reduction gearing.

PUMPS.

As I stated in the introduction, the direct driven turbo-centrifugal blower presents no difficulties, as peripheral speeds can be selected suitable for both turbine and centrifugal blower or fan.

The geared turbo pump, however, offers many advantages, and in the near future will, I think, enter into severe competition with the present system of driving the ram and centrifugal pump, more especially with the latter and increasingly adopted system of the two (Fig. 5).

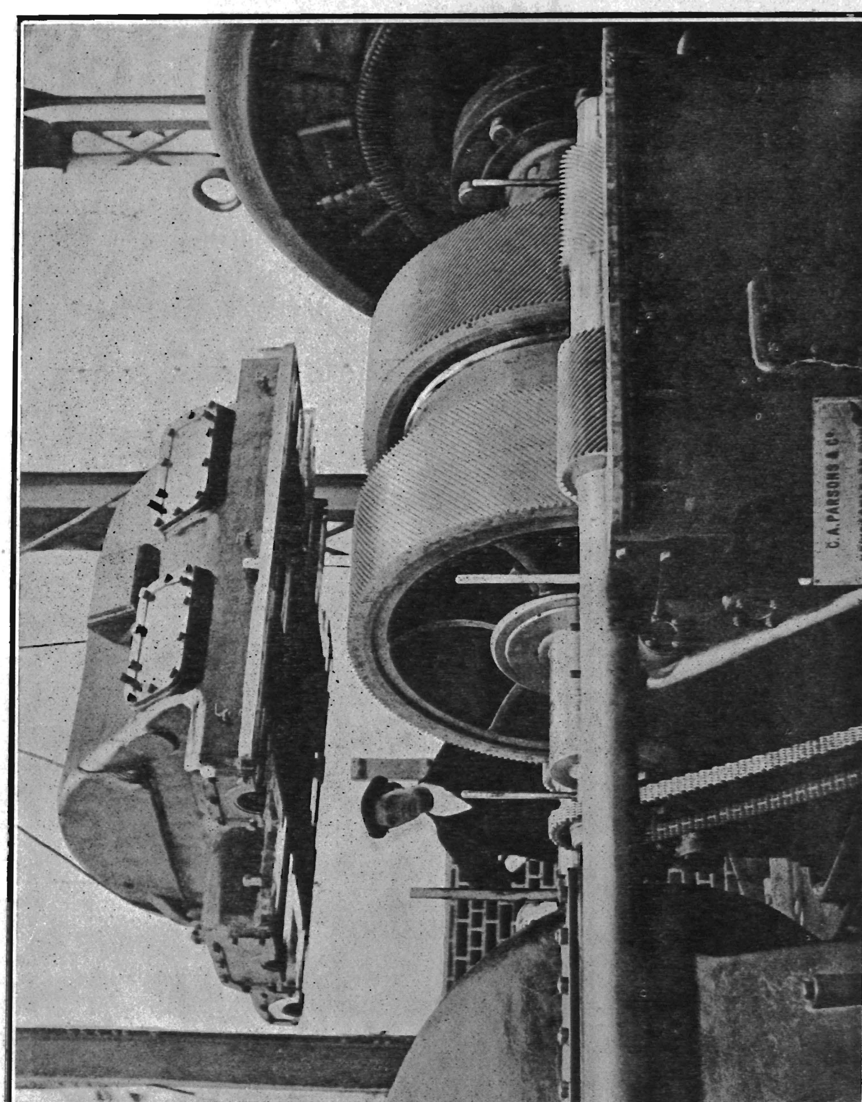

Fig. 5

It has been found, with direct coupled turbo-centrifugal pumps, that it is most difficult to design an efficient pump without adopting refinements in design distinctly unfavourable from a running and overhauling point of view. By adopting a geared turbine drive, it is possible to adopt any well-tried make of centrifugal pump, which has generally superior efficiencies compared to pumps running at similar speeds to the turbine, and the sacrificing compromise of turbine speeds decreasing and pump speed increasing, inherent with the direct coupled system, is abolished.

It will interest you to know that the first turbo-geared centrifugal pumping plant is now being manufactured for the Metropolitan Board of Water Supply and Sewerage, Sydney, for their Crown Street Pumping Station. This plant is designed to pump 7,000 gallons per minute against a total head of 192ft. The turbine is 510 b.h.p. at 5,000 r.p.m., geared to an ordinary standard slow-speed centrifugal pump running at 980 r.p.m., the ratio of the double helical reduction gear being about 5:1, with steam at 160lbs. pressure, superheated 120deg. Fah., and a vacuum of 28½in. (Bar. 30in.), the guaranteed steam consumption per b.h.p. being 12.6lbs.

MILL.

The geared turbine, with its still short history, has found favour for mill driving. The first application was in 1910 for driving a large 3-high plate-rolling mill at Messrs. Dunlop's Iron Works, Scotland. This company first considered a scheme for utilising the exhaust steam from the existing mill engines for electrically driving a new mill, and it was proposed to utilise a large existing fly wheel, weighing with its shaft about 100 tons, for equalising the load on the dynamo and motor.

This fly wheel, being found sufficiently large to make an almost constant load on the mill, the possibility of cutting out a constant loss of about 15 per cent. in electrical transformations, and substituting a relatively cheap mechanical reduction gear with a loss of only 1½ per cent., was investigated, and finally decided upon. The turbine is of 750 B.H.P., at 2,000 r.p.m. The speed of the mill is 70 r.p.m., the reduction being made in two steps.

The slabs rolled are about 13 cwt. in weight, with a thickness of 4in., the finished plate being 5-16in., and the finished width 63in.

During the heaviest passes on the mill, between 2,000 and 3,000 h.p. was being used, but records show that almost double this power has been given out during short intervals of very heavy passes.

I saw this plant in operation in 1912, it being the first I had seen working. I examined the gears, and, although the plant had then been in operation about two years, I could neither see nor feel any signs of wear of the gear wheels.

This type of turbine is being largely adopted in textile mills, and a short description will give you an idea of the suitability of such plant for this class of work.

About three years ago a Calcutta firm investigated the possibility of utilising exhaust steam turbines instead of installing another reciprocating engine, with the idea of reducing their power costs. The result of this investigation demonstrated that if the turbine had to generate electricity, and drive the shafting by motors, little or no economy could be expected. But by installing a geared turbine arranged for rope driving the mill, economies could certainly be attained, and a pure exhaust geared turbine was installed of 700 h.p., at 3,000/300 r.p.m., and for the first time reciprocating and rotary steam plants driving through ropes were put into parallel with the most satisfactory results, both from the point of steam consumption and even turning moment (Fig. 6).