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THE MECHANICALLY GEARED STEAM TURBINE.

(By W. H. GRIEVE.)

In choosing the subject of my paper to-night I have the advantage of breaking fresh ground as far as Australia is concerned, and although most of my matter has already appeared in the technical press, it is probable that only a few members have taken more than an ordinary interest in the subject. If I am in error in this respect, I hope they will excuse a reiteration of material presented mainly by the Hon. Sir Chas. Parsons in papers before the British Naval and Engineering Institutes.

I am not in any way excusing the subject, as it appears to me to be the most important development in Steam Engineering since the invention of the steam turbine.

One cannot altogether ignore the historic side of this matter, as it means the re-introduction of a very old principle—the introduction of mechanical gearing to improve the over-all efficiency of a steam plant working, when direct coupled to electrical and marine machinery, under great disadvantages, and in some cases precluding the use of the steam turbine completely.

In the old days of mechanical gearing—I refer to marine work—the gearing served an exactly opposite purpose, increasing the speed of the propeller compared with the then very slow revolving marine engine. And in this respect the re-introduction is a very interesting example of the reversion to old principles.

I propose to-night to take in a very large field of Steam Engineering, and to refer briefly to the application of the geared steam turbine to each; so I hope you will overlook my boldness in this respect, as each application is, I think, worthy of a paper of its own.

As the Hon. Sir Chas. Parsons prophesied at a very early stage in the history of his invention, he looked to Marine Engineering as offering the greatest scope for the turbine.

This latest departure of his certainly opens up an enormous field, which up to date has been more or less closed against its application. I refer to the ordinary tramp and slow-speed steamers, and for the first time the monopoly of the triple and quadruple expansion engine is seriously challenged for marine propulsion for all classes of boats, mill driving, and the generation of a D.C. electrical supply.

The steam turbine, depending for efficiency upon certain fixed ratios of steam and vane velocities, is an essentially high-speed machine compared with other heat engines, and commercial rivalry tends to procure an ever-increasing power from a given weight of material and workmanship; and in no branch of Engineering has the selection of material to stand the increasing stresses received such careful consideration as in modern turbine design.

Only a few years ago a peripheral blade speed of 300 feet per second was considered normal practice; now 600 and 700 is ordinary practice with certain types of turbines, and wheels have been tested up to 1,000 feet per second, which is closely approaching the velocity of sound.

The geared turbine is the outcome of a long endeavour to improve the velocity ratios of steam and turbine vanes, more especially of marine steam turbines, which steam and vane ratio or co-efficient is known as symbol "K," denoting relative efficiency, and is calculated in Parsons' design as follows:—

$$K = \frac{\text{Revs}^2 \times \text{Rows} \times \text{Mean Dia.}^2}{10^{-6}}$$

Speed of revolution is therefore of the first importance in all turbine designs, but only in a few cases has the turbine designer had a free hand, as in nearly all branches of commercial Engineering the speed of the direct coupled turbine is decided by the machinery to be driven, and in the case of turbo-alternating machinery is even taken a step further, as the periodicity of the electric supply decides the speed of alternator, and so the turbine.

No compromise is possible, and the turbine designer is given one or two speeds—say, 1,500 or 3,000 revs.—which he must adopt. However, this particular combination generally allows for an efficient plant.

In the case of direct coupled D.C. turbo-machinery, the turbine designer is in a very difficult position, as the limiting factor of the armature is reached so very much earlier than is the spindle of the turbine, the limiting factor being the peripheral speed of the commutator and commutator rings. So that direct coupled turbo-machinery of 1,000 k.w. has given the best all-round results at speeds of about 1,500 r.p.m., whereas if the turbine designer had had a free hand the speed would have been about double that figure, the slow-speed turbine resulting in a relatively inefficient and expensive machine.

With the turbo centrifugal blowers, or compressors, there is not so much difficulty in constructing the revolving elements to suit the desired speed of the turbine.

In the case of turbo centrifugal pumps, the efficiency of present-day designs are superior at speeds too low to allow for direct coupling to efficient steam turbines.

Until the introduction of the geared machine, the steam turbine was completely shut out from direct mill driving, the speed of the direct coupled machine being much too high for rope driving. This is now altered, and alone opens up a huge new field for the steam turbine.

And finally, but most important of all, is the marine steam turbine. It is here that one realises that compromise means great sacrifice in the combined efficiency of any plant, and the compromise is made greater in this branch of turbine Engineering than in any other.

Only in fast cruisers and destroyers does the speed of the marine turbine approach those of similar-sized plants used for land purposes, and this condition only prevails at full-speed. This is due to the impossibility of designing an efficient, high-speed, high-power propeller, which is largely on account of cavitation troubles.

As weight and size of marine turbines is a more important item than on land, the marine turbine co-efficient for direct coupled turbines has only been about half that of land turbines.

The horse-power varies almost directly as the square of the revolutions for turbines of similar designs, so it will be seen that for equal powers, weights per h.p. are very high in marine turbine work—where direct coupled propellers have to be considered—compared with land turbines, which is another distinct disadvantage of the direct coupled system.

The following examples will show to what extent the speeds of efficient land turbines have varied from marine turbines of approximately equal power:—

Taking the case of the two express Cunarders—"Mauritania" and "Lusitania"—the total power of each being 70,000 h.p., divided into two separate steam systems of 35,000 h.p. each. These turbines only revolve at 180 revolutions, whilst on land turbines of equal power would revolve at about 750 r.p.m. There is an electrical generating set now running of about this power and speed.

The 10,000 k.w. sets for the Victorian railways will revolve at 1,500 r.p.m.; a direct coupled marine turbine of equal power would only revolve at about 200 r.p.m.

As already stated, the weight and bulk of a turbine with a given co-efficient varies almost inversely as the square of the revolutions. It follows that the higher the speed the less is the weight and the smaller the bulk.

The typical large L.P. turbine cylinder, although completely reliable in practice, possesses a great many constructional difficulties, and is extremely expensive on account of the large gun-like forgings necessary for the revolving spindles.

In the high-speed turbine of equal power the blade clearances would be made relatively smaller, with the resultant saving.

The large dimensions of the turbine spindle of high power for direct coupling to the propeller and shaft has always had the effect of making those responsible for the design dubious as to the advisability of using superheated steam, on account of the unequal expansion of the different materials employed, and, what is of really more importance, the effect of high superheat upon the cast-iron cylinders.

It might here be mentioned that with turbines suitable for superheats of over 50deg. Fah., the high pressure portion of the cylinder is made of cast steel, which is not subject to the growth of cast-iron under high superheat.

The relatively high-speed turbine greatly reduces the diameter and size of the marine turbine, and in so doing makes it possible to utilise superheated steam. A very large saving is now possible in this direction, and in a few years equal superheats to those now used in central stations will, in all probability, be in vogue in marine work, with the large resultant saving upon present saturated steam conditions.

I hope the foregoing examples demonstrate the manner in which the desired speed of the turbine has been interfered with by considerations external to the turbine itself, and will allow you to appreciate what an important step it would be to allow the turbine designer an unfettered control of the speed of the turbine without having to take into consideration speeds of electrical plant or propellers, and inversely what it means to the electrical and propeller designers to have equally free hands in the selection of efficient and reliable speeds. This double emancipation reacts in favour of increased over-all efficiency and reliability of plant.

It will now be my endeavour to put before you how this disadvantage has been removed by the Hon. Sir Chas. Parsons by the introduction of a suitable reduction gearing, and to what extent the introduction of accurately cut mechanical gears has opened up enormous new fields of work for the steam turbine.

GEAR CUTTING.

But before giving examples of the geared turbine I want to briefly describe the construction and working of the gear wheels, and Parsons' patent creep system of cutting these double helical gears.

As you know, Dr. De Laval first introduced the single and double helical reduction gear for his small high-speed turbines, and it is strange that since he did, so many years ago, it was not developed for larger powers. The reason for this is largely, I believe, on account of the absence of suitable machine tools for cutting the wheels.

In 1897 the Parsons Marine Co. equipped a steam launch with a 10 h.p. turbine, revolving at 20,000 r.p.m., geared to a propeller running at 1,400 r.p.m., through a single helical spur gearing; and several experimental small turbo dynamos were also constructed.

The gears were cut by an ordinary universal milling machine, and, as he states, "without any special precautions as to accuracy"; and, although the teeth were obviously irregular, he was surprised at the good way the gears ran, and the good efficiencies procured. But these gears were very noisy.

In evolving a high-speed mechanical gearing, high efficiency with silent running is all-important, and it is more with respect to the latter factor that the real progress has been made in the last year or two.

For instance, the experimental gears constructed by Mr. Parsons in 1897 has an efficiency above 98 per cent., calculated by the method of heat loss. So that really, from an efficiency standpoint, no radical improvement has or could be made in this respect.

The great improvement is the absence of noise; with the old 1897 gears it was almost impossible to stay for any time under the same roof if such a set were running. And even in twenty years the great advance in the manufacture of gear-cutting machinery did not permit of the manufacture of quiet running gears.

There being no sound standards, it is only possible to compare the noise (for the want of a better word) with that made by other types of machinery.

With the Parsons' patent creep cut gears—which have completely solved the problem of cutting quiet running, highly efficient double helical gears, and which I shall shortly describe—the noise made by geared plants is infinitely less than the noise made by direct coupled D.C. turbo plants.

Taking, for example, a 4,000 k.w. D.C. geared set, the gearing is inaudible outside the building, while the noise heard standing alongside the gear-box is not sufficient to prevent conversation in an ordinary speaking tone of voice—not the usual power-house tone.

And, compared to the noise of turbo-alternators, which you all have heard, the geared machine is much quieter than a quiet 50-period alternator of equal capacity.

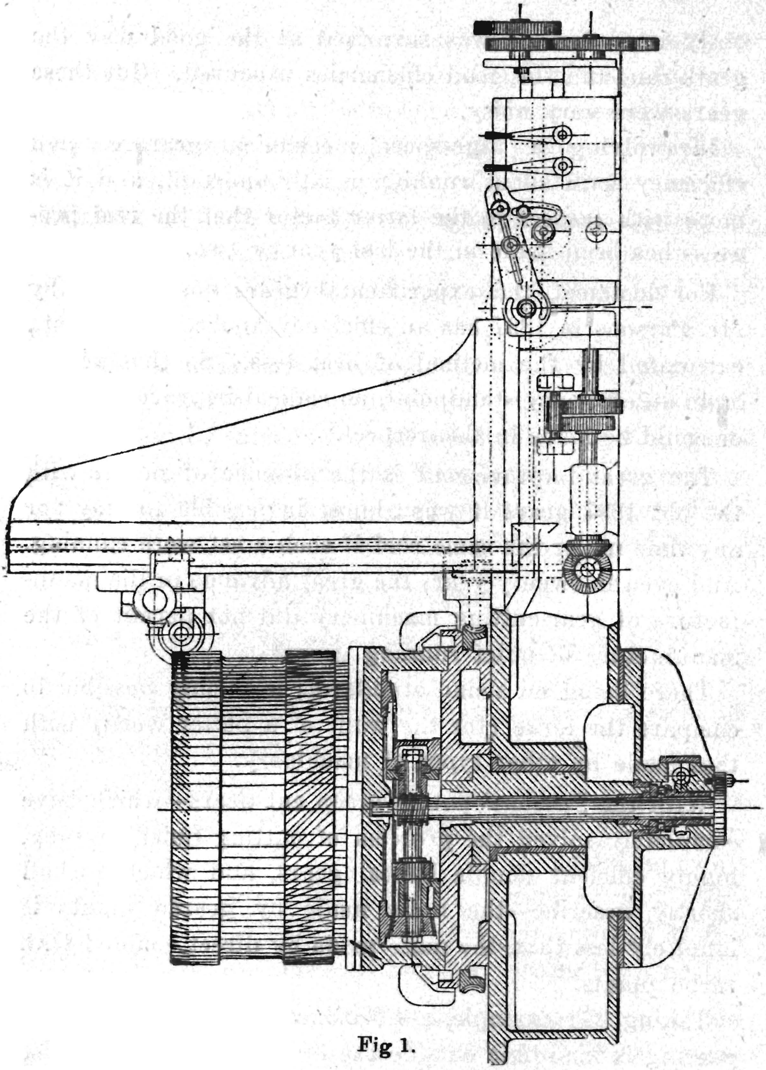

Fig 1.

CREEP.

Gears cut by the most accurate and elaborate gear-cutting machines were found noisy in operation, and this disadvantage would have greatly limited the application of the geared turbine, and certainly have prevented its use in the majority of central stations (Fig. 1).

Thorough investigations were made as to the noise-producing cause, and with the assistance of the microphone oscillograph it was proved to be due to slight or almost miscroscopic inaccuracies in the teeth, the source of which was found to be in the parent gear of the gear-cutting machine, i.e., the worm and worm wheel for revolving the table on which the wheel being cut is mounted.

This error is, of course, due to inaccuracies in the machinery which cut the worm and worm wheel; and it has been suggested that the real cause is hereditary, going back some "generations" of worms and worm wheels to the first hand-cut screw.

The problem, therefore, was to devise, if possible, means of cutting these gears whereby the inaccuracies of the parent gear of the cutting machine would not be reproduced in the wheel being cut; but it is impossible, of course, to completely eliminate such a defect.

It is possible, however, to so distribute the defect over different parts of a single tooth—in other words, to destroy the periodicity and so the resonance—that it is reduced to an almost negligible quantity, resulting in quiet running gears.

One method was to supplement the standard single worm drive with a multiple drive consisting of, say, a number of worms driving one worm wheel; by so doing, individual inaccuracies would, to a considerable extent, neutralise each other.

The patent creep system goes very much further.

In the first instance its aim was to destroy the periodic error, but the system, in addition, very considerably reduces the actual magnitude of the error.

To repeat the words of Sir Charles Parsons:—

"It will be seen that in the process ordinarily adopted, in which the work is mounted on a table rotated by means of a worm and worm wheel, the latter being attached

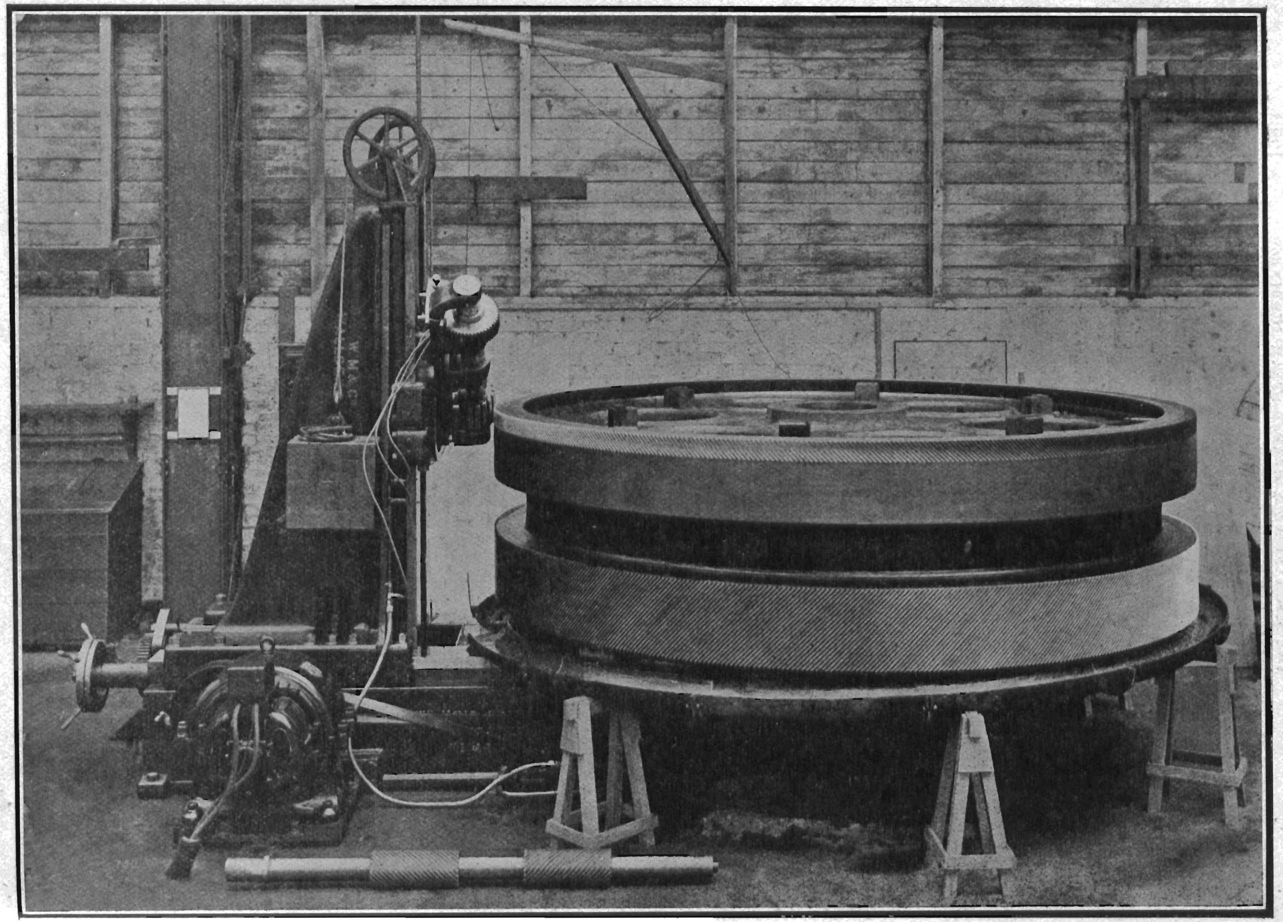

Fig. 2

permanently to the table, the errors will be some function of the angular position of the work, and, therefore, lie in planes through the axis of rotation; and if, as is mostly the case, the errors of the parent gear are periodic, these planes will lie at equal angular intervals, and will come into mesh periodically. Now, it will be seen that, if the work is given a small steady advance in relation to the table, the errors, instead of lying in planes through the axis, will lie in spirals around the wheel, and that when put to work they will be obliterated and leave a true wheel."

The supplementary table is given a certain percentage creep in advance, by the train of gears shown, in relation to the original table, and to keep the same rotational speed, the main or parent worm wheel driving the lower and original table is driven the same percentage slower. These percentages amount to about five.

Whilst this relative motion resulted in the destruction of the periodicity of the cutting errors by making such errors lie in very oblique spirals around the wheel, the magnitude of the actual error, i.e., the difference in the position of cut, has been reduced to about one-fifth of the original error.

When it is considered that the original error amounted to a double amplitude of about four thousandths of an inch in the parent worm and worm wheel of the gear-cutting machine, you will appreciate what a degree of accuracy this creep system has introduced, and it seems possible that if a gear-cutting machine were fitted with a worm and worm wheel cut by this patent process the error would still further be reduced.

The gears are always arranged with a "hunting" tooth, so that engaging teeth have a relative motion one to another at each revolution. Oil is supplied in continuous streams directed on to the point of mesh. The pinions