

up a theory the "methodical arrangement of facts" must be complete. Imagine a paddle-steamer in a fixed position relative to the motion of the earth, and the wheels driven by the water revolving with the earth, and you have the idea of the mill stream mounted on an axis. Being in possession of a theory which appears to be sound, it remains to be seen whether it can be applied within the limitations of known or achievable practice.

It is probable that machine-cut teeth are not always correctly shaped, although the machines ensure the equality of their pitch. The bearing between opposing teeth may be only at a point, or points, instead of on a line the full width of the wheel. Even this line contact, when acquired, is not a mechanical ideal. Teeth slide as well as roll, and concentrated pressure and friction are, therefore, of great importance, and it is only the high quality of the material available that enables thousands of horse-power to be transmitted through one, two, or three lines of contact of one, two, or three feet lengths.

The value of the oil film and its existence between the engaging teeth are apparently accepted by authorities on gearing, and I sincerely hope that the acceptance is justifiable. If this film of oil is actually constant, it must be concluded that the pressure, the wear, and the transmission, are all effected through the medium of that oil film. It is estimated that in modern high-speed gears, the period of contact is about one-thousandth of a second, and from that fact is deduced the retention of the oil film.

From the foregoing it may be reasoned that the thicker the film the better, and, to carry this reasoning to its logical end, if the teeth of one wheel were eliminated and only the oil left, the theory of the endless mill-stream and the earth-driven paddle-wheel would be realized in practice. Absurd again, of course, but the question resolves itself into one of degree. How near can one get to a continuous oil film? The fluidity of oil makes it impossible to retain it in the form of a pinion rim of sufficient thickness to engage the teeth of the spur, so something else must be considered. If the oil is solidified the effect is no better, because, even if the radial forces suspended action, one revolution of the pinion would give it the impression of the spur teeth and destroy the continuity aimed at.

Reverting to the rational forms and materials of gear teeth, the finer the pitch the closer together, and therefore more nearly continuous, become the successive films of oil. If, however, the teeth are made too fine to carry the load, all the advantage would be lost, and it must be concluded, for the present at least, that the continuous film is impossible in practice; but there is an element which has not yet been considered. It is neither a fluid nor a solid, and yet possesses something of the na-

ture of both. It is sometimes called a semi-fluid, and perhaps the only familiar form of it is to be found in balls. If a number of balls are poured into a vessel they will find a common level; if run out on a table they will behave much like water.

A less familiar form, perhaps, found in rollers, and here is an element which can only flow in two opposite directions. It is this fact, this limitation, which enables it to be harnessed in the form of an endless mill-stream within the compass of an ordinary pinion, Figs. 8 to 19. These figures show how this semi-fluid can be controlled and kept in its appointed place. The density of the element may be varied by having more or less rollers in a given space, and each roller being supported by all the others; their individual diameter does not materially affect their strength as a combination, which, in fact, forms one solid "fluid" tooth, equal in thickness to almost the circumference of the pinion.

Reverting to the "absurd" proposition of a continuous oil film it may be seen how nearly approach has been made to its realization. It is at once apparent that each roller provides a line of contact with the engaging wheel tooth, so that, instead of one line of contact per tooth, there is a number varying with the depth of gear mesh. Further, each roller has a film of oil over its entire length and circumference, therefore, there is actually that continuous oil film which was previously thought absurd. Not only that, the metal-roller element upon which the film is built is almost as fluid as the oil itself.

Having now completed a brief and rugged analysis of the theory and construction of a pinion designed to fulfil certain requirements, more particularly that of adaptability to varying conditions, there remains to be set forth, in a few words, its application to power transmission and the extent to which it meets those requirements. It may be easily seen that a pinion of this construction is able to accommodate itself to any straight tooth in a wheel, and will continue to do so until the tooth is entirely worn away. It is, therefore, independent of the contour and thickness of the tooth. Also, the tooth may engage with it at any point of its circumference, and it is thus independent of pitch. These facts indicate the elimination of geometrically designed teeth as a necessity, and also, that irregularity of pitch and missing teeth will not interfere with smooth and continuous running. Further, there are no tooth clearances, and therefore no backlash. Other irregularities are provided for in the fact that the rollers are free to incline in either direction across the face. The alignment may be faulty, parts may expand or contract, the foundations may warp and twist, but the little rollers will cling to the teeth of the wheel till it is ready for the scrap heap.

It is, perhaps, at sea with double-reduction gears and turbines that "varying conditions" are most pronounced

and in this connection I will at this point introduce some notes of an expert.

Some Notes on Behavior

"In vessels fitted with single-reduction gearing, the teeth should not suffer from the 'shock' forces which break or tend to break propeller blades, as the teeth are sufficiently strong to safely transmit the forces to the turbine; by so doing the speed of the turbine rotors is reduced, or may even cause them to stop or reverse when the forces tending to break the propeller are great. By this action the single-gear turbine acts as a cushion to the teeth, and it is for this reason that there are many successful steamers sailing today with this type of gear. But in the case of the double-reduction geared turbine this would not be the case, as the secondary pinion spindle carries the heavy primary gear wheels, which are virtually fly-wheels humming at between 500 and 600 revolutions per minute—the effect of which is to lock and damage the teeth when the propeller blades are breaking or tending to break.

"As the section at the root of a tooth on the main gear wheel of, say 4 feet 6 inches radius is very small when compared to the section of a propeller blade at 4 feet 6 inches of a 400-foot cargo steamer, and although there is about a three-tooth section in contact, it is only natural to assume that when destructive forces are tending to break the propeller blades the teeth will give way instead. The second-reduction pinion with helical teeth requires a slight fore and aft play, which becomes a fore and aft shooting of pinions and spindle, upon its well-oiled bearings, when the vessel is pitching, rolling, and butting into the waves."

It will be readily understood that the fore and aft shooting of the pinions referred to in these notes might have a very serious effect on the gear, and in the case noted it was so severe that every alternate five teeth in the main wheels were damaged by the impact. This effect was found to have its cause in the use of helical teeth, the pinions being shot to and fro by the action of the inclined planes in motion. This end-play had increased to $\frac{5}{8}$ inch in the case cited.

Helical gears were first suggested by Dr. Hook, of Cambridge, with the object of obtaining continuity of engagement and smoothness of action; but, in cases like that cited, these virtues are not necessarily present. From what has been said of the new gear it will be gathered that these objects are expected to be gained with simple straight teeth; it has been claimed that the Autopitch pinion will mesh accurately with any straight tooth of whatever shape or thickness, but there are, no doubt, certain forms which will give better results than others. This presents a problem more difficult to solve than that of the pinion itself. In most of the trials carried out existing wheel patterns have been used, but it is intended to make experiments with teeth of various forms, and to compare results. One important point may be mentioned.