PROPOSALS for MILL TESTING

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The Need for Tests

Study of all the technical aspects of mills has relied on three main sources; written, oral, and the examination of surviving mills. These sources can provide information on mill design over long periods, and on working methods, mainly in recent times. However, they give little quantitative information on the performance of individual parts of the mill which could enable us to study the relation between performance and design, and to compare mills in different regions, and of different ages.

Although some performance data - particularly performance limits - can be deduced from the mill design, most of it does not permit theoretical analysis. The only solution is to make practical tests.

Quantities to be Measured

The obvious need is for measurements of power input, mechanical power, and product output. These are easily defined for watermills, but windmills demand some quite different concepts which are not yet formulated. These proposals are therefore confined to watermills for corn milling.

In tracing the power through the mill, there are three important conversion stages; hydraulic input to power at the wheel shaft, power at the wheel shaft to power at the stone spindle, and power at the stone spindle to grinding rate. Some of the measurements required to fully quantify them are easily made, but others present severe difficulties.

Speed, fall and grain flow are easily measured, and water flow can be measured with more or less difficulty, depending on the design of the mill, but torque measurement presents a serious problem. For this reason, the few mill tests which have been made are seriously deficient, as no attempt was made to measure torque. This means that we have no real idea of the power involved. Such tests were also restricted in that they were confined to a single mill, and did not explore the full range of its performance.

A new testing programme is needed which overcomes these limitations.

Resources

The ultimate limitation in carrying out such tests is cost. We obviously lack the resources to build even substantial parts of a mill as a test object, so we can only use existing workable mills where the co-operation of the owners can be obtained.

This severely restricts the test methods, as it precludes almost all alteration to the mill. This increases the difficulty of torque measurement, which can only be done by measuring the deformation of some elastic part in the drive train. In practice, some kind of spring must be inserted in the train, or the elasticity of some existing part must be used.

Using the elasticity of an existing part is attractive as it requires no alteration, and is used in some situations, such ship's propellor shafts. Unfortunately, mill shafts are as a rule generously sized, short, and made of low-elasticity material such as cast iron, so they will not twist through a large enough angle to provide useful measurements. For example, a 60 mm diameter stone spindle with a length of 500 mm between the stone nut and the bedstone would twist about 0.09 degree with a load of 8 kW at 120 rpm.

Inserting a spring presents obvious difficulties, as the design of such a device is subject to severe restrictions. To be acceptable to a mill owner, it must be easily installed without major dismantling or altering any mill part, and not cause any risk of damage to the mill during operation. It must also be low-cost, or constructable with facilities available to us, and be adaptable to more than one mill.

There appears to be only one point in a mill which could accomodate a transmission dynamometer meeting these requirements. Where the stones are hung on bar-type balanced rynds, it could replace the mace. The runner stone would have to be lifted to fit and remove it, but that is a routine operation which hardly amounts to dismantling, and nothing need be altered.

The Transmission Dynamometer

Assuming a maximum power into the stones of 8 kW at a speed of 120 rpm (12.6 rad/sec), the maximum torque would be 635 Nm. The drive is normally applied to the rynd at a radius of about 70 mm, which requires a force of about 7.44 kN, or as each side of the rynd is driven, 3.72 kN per side.

Constructing a spring to transmit such a force with measureable deflection which will fit within the space normally occupied by the mace is a difficult problem, and a more promising approach seems to lie with a hydraulic system. Replacing the mace by a structure fitting the stone spindle and carrying two hydraulic cylinders with their pistons bearing on the driving faces of the rynd would allow the torque to be measured by a bourdon-tube pressure gauge.

Such a device could be largely built out of standard parts, some of which could be obtained as scrap. Car disc brake cylinders appear to be about the right size, and would provide cylinders, pistons and seals. Some of the outer parts of the cylinders would have to be cut away and new pipe connections provided, but that should be within the capacity of a home workshop.

The maximum pressure would be about 1.9 MPa (19 atm) which is well below the pressures encountered in their original use. There should be no difficulty in obtaining a pressure gauge for this range. Water might be a better filling than the usual hydraulic fluid, as it would not contaminate the stones in the event of a leak.

The structure would have to be made, preferably fabricated from steel plate. The problem of fitting it accurately to any spindle taper could be solved by lining the hole with loose plates, backed with screws. This would allow it to be adjusted to suit almost any mill with a balanced rynd.

The final problem is how to read a rotating pressure gauge. The obvious solution is to use an electrical pickoff. If a linear variable differential transformer was attached directly to the end of the bourdon tube, it could be driven by a single chip (NE5520) and the output fed by a cable lying in a hollow in the damsel to a slip ring at the top of the damsel spindle. The torque could then be read with a voltmeter.

If springs were adopted instead of the hydraulic system, the linear variable differential transformer would be equally suited to providing a remote indication of their deflection.

The dynamometer would need to be calibrated, but this could be done by attaching weights to a cord wrapped round the runner stone.

Flow Measurement

Several methods are available for measuring water flow, and choice would be greatly influenced by the design of the mill under test. The most promising is probably the pitot tube. It is easily made, it can reach into awkward locations, and its calibration can be calculated with fair accuracy, which is likely to be sufficient for this application. It measures velocity rather than flow, but that is a quantity worth measuring anyway, if applied to places such as the wheel intake. The area at such a point is easily measured, so the flow could be deduced.

Lode Mill, No. 52/212, which is operated by the Cambridge mill Group, has been suggested as a possible test site. It has the special advantage that the river authority maintains a gauging weir immediately below it. As it carries only water from the wheel when the mill is operating, and the calibration figures for it are available, flow measurement there presents no problem at all. It would therefore be a good choice for the start of the programme, as one new measurement technique could be avoided while experience was gained with the others.

Test Programme

Although a comprehensive test on a single mill should give valuable results, even more might learned by testing a variety of mills. The number need not be large, for what matters is variety. Ideally, this would include all the main types of waterwheel, and all the common types of millstone, working on a variety of products. If the power input to the stones could be measured, the waterwheel and milling measurements would become independant. This would allow the entire programme to be covered on five or six mills, if enough suitable mills would allow us the facility.

To get the maximum benefit from such work it would be essential to test over a wide range. Feed, tentering, and speed should be varied over the greatest range that can work, which would thereby both load the waterwheel over its whole range, and thoroughly explore performance of the stones. Besides measuring speed, torque, water flow, and grain flow, it would be essential to record the grain type, its moisture content, and the properties of the meal such as particle size distribution (by test sieving).

These proposals still contain two serious limitations; there is no means of measuring the torque applied to the waterwheel shaft, and the transmission dynamometer could not be applied to a stiff rynd. These make it impossible to separate the efficiencies of waterwheel and gearing, and exclude oatmeal milling from the programme.

In the absence of proper measurements, an estimate of the gearing losses might be made by using the transmission dynamometer calibration setup to find the torque required to just turn the mill. Adjusting and observing a critical weight load is troublesome under dynamic onditions, but the transmission dynamometer would provide a convenient check. It would turn the mill backwards, but that would be the correct condition, as it would use the normal driving faces of the teeth. As it seems likely that bearing friction will prove to be the main loss, the no-load and full-load losses should be similar.

Oatmeal milling could only be tested by devising a different torque measuring system which did not depend on the balanced rynd. This problem has no obvious solution within the restrictions laid down earlier, so there is no choice except to postpone the question until tests on the simpler forms of milling have been completed.

Aims of the Programme

The direct aims would be to obtain reliable figures on the efficiencies attained in practice for the common forms of waterwheels and gearing systems, with at least an indication of the contribution of each, and accurate data on the relationships of speed, power consumption, and output of millstones for a variety of products.

This information should shed new light on such questions as; How far could the waterpower resources of a region support the local population at various stages in its growth ? What practical gain was there from various innovations in mill design, such as the spurwheel gear? In mills with several pairs of stones, how many could really be worked at once, and with what benefit? Is there any firm connection between the number of pairs of stones in a mill and its output ?

It also seems probable that other questions would be both raised and answered from the data itself, once it was available. It should also put an end to the baseless speculation on these topics, which has been a feature of writing on mill history from its beginning.