ANALYSIS OF THE DAMSEL & SHOE FEED CHARACTERISTICS

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At first sight, this mechanism appears to have little worth analysing. All that was normally demanded of it was that it could be adjusted to give a steady feed at whatever rate the miller chose, and that once set, it would maintain that rate. That it gave satisfaction is obvious from its almost universal use.

In maintaining its feed rate, it was not usually troubled by frequent or rapid changes in external conditions. If the feed rate - or anything else - changed slowly, the miller would simply readjust.

However, there was one important exception. The speed of a windmill often varied continually, over a substantial range, and manual intervention was not feasible. Under gusty conditions, it would have left the miller with no time for anything else. The solution - apart from putting up with the ill effects of varying speed, whatever they were - was the to install a millstone governor.

The action of the governor remains mysterious, and none of the proposed explanations are convincing. Mr W N T Roberts recently summarised the various theories which have been proposed, such as reducing the speed variations by changing the mechanical load, compensating for the changing grinding efficiency, or feed rate, or "the tendency of the stone to rise" as the speed increases (as claimed by Rex Wailes, but without any convincing reason).

The weakness with all the suggestions to date is that they do not explain why a change of speed should demand any corrective action at all: if the stones turn faster, they grind faster, the feed increases, so what should change except their output?

The question has also been considered by Mr P J Jarvis, who decided that compensating for the changing feed rate with speed was its most likely purpose. It appears obvious that the feed rate must vary with speed, but if it is proportional to speed, an increased feed rate must be matched by an increased grinding capacity from the stones, and should leave the grinding quality unchanged. However, if the relation between speed and feed rate is not linear, grinding conditions will change with speed. He planned a series of tests to determine this relation, but has not yet had an opportunity to carry them out. He also proposed a power law to describe the results, as the easiest type of curve-fitting for the simple non-linear law he anticipated.

For me, this suggestion raised the question of why should the law be non-linear? If it was so, it should be possible to find the underlying mechanism, and analyse it. Such an analysis would not remove the need for practical tests, but such tests would gain a wider validity if they were shown to have a theoretical basis. Constructional details of such parts vary from mill to mill, and it scarcely seems worth the effort of testing more than one, so if the results of one such test conform to the theory, we might assume that the general behaviour of all such mechanisms was established.

The Action of the Mechanism.

As the exit of grain from the hopper is controlled entirely by the level of grain in the upper part of the shoe, we can ignore it and consider only the shoe. At rest, grain lays along the whole length of the shoe, which is at too shallow an angle to allow the grain to slide. The grain may form a thick or a thin layer, depending on detailed design and operation. Where the layer is thick, its lower end comes to rest at a stable angle (Fig.1.).

Shaking the shoe will have two types of effect, due to vibration and lateral acceleration. Lateral acceleration, provided it is sufficient, will cause grains in contact with the shoe to slide, and once moving, the horizontal component of the reaction to their weight will cause them to move down the shoe. When the grain forms a thick layer, lateral acceleration will detach grains from the end with a shearing action, and when they are detached and fall, the rest of the heap moves down to re-establish the stable angle. As the damsel shakes the shoe laterally, these are clearly the main actions, but there are others. Each blow from the damsel will set up vibrations, in many modes. One at least, will be vertical, with the effect of momentarily reducing the cohesion of the heap by diminishing the effect of its weight, and removing the friction against the shoe by bouncing the grain off its surface.

These effects are far too complex to analyse, and in any case, they will depend on the detail design of the shoe. However, it is probably sufficient to assume that they all behave similarly, by causing an amount of grain to be dislodged proportional to the energy imparted to it.

The damsel can be considered as a set of circular lobes, of such a small diameter they can be regarded as points. One such lobe would give the shoe a sinusoidal motion, provided that the shoe is held against it with sufficient force to keep them in contact. The effect of several such lobes is shown in Fig.2. It is drawn for four lobes, which is probably the commonest number, but the use of other numbers does not affect the argument.

When contact passes from one lobe to the next, the movement of the shoe apparently changes direction instantaneously. This is an infinite acceleration which implies an infinite force, so in practice the force must be limited by the elasticity of the material, storing energy which will then be released as vibration. This action will be modified at very high speeds, when the force holding the shoe against the damsel becomes insufficient to provide the acceleration needed to keep them in contact. However, observation of working mills suggests that they never reach a speed which would cause this to happen.

The gross motion of the end of the shoe can be expressed in terms of the radius, number of lobes and speed of the damsel.

$d = r \text{ Sin } wt$ where d = displacement of the shoe,
r = radius of the damsel
w = its angular velocity, & t = time

$V = wr \text{ Cos } wt$ where V = velocity of the shoe

For a 4-lobed damsel,

$v = 0.707wr$ where v = velocity as the motion is about to reverse

At this instant,

$E = mr^2w^2$ where E = energy imparted to the grain
m = mass of grain

The usual factor of 1/2 is absent because the velocity is taken as 2v. This is because the change of velocity is from v to -v.

If the quantity delivered per blow of the damsel, Q, is proportional to energy

$Q = cmr^2w^2$ where c is a constant of proportionality

The grain flow, F, is the quantity per unit time, so

$F = nNQ$ where n = number of lobes on the damsel
N = damsel speed in revs/sec

$= cnNmr^2w^2$

$w = 2 N$ and $n = 4$ so

$F = 16cmr^2N^3$

The additional constants, together with the mass which cannot readily be quantified, can be gathered into a new constant of proportionality, k, when

$$F = kr^2N^3$$

This result is not quantifiable, as it contains an arbitary constant. Establishing a value for it by analysis may well be impossible, and is certainly not worthwhile. The value of the result is that it justifies the power law, showing that the feed rate is proportional to the cube of the speed. It is based on the assumption that the quantity of grain dislodged per blow of the damsel is proportional to the energy imparted to the system of shoe with its grain content. This seems reasonable, but is not proven. It would be best established by experiment, and the Group's planned testing programme should be able to include this.

If the assumption fails it seems likely that it would be because the dislodging mechanism was less efficient than suggested here. In that case, the characteristic would still be a power law, but with an index less than three. The effect is shown in Fig 3, for a feed rate normalised at 120 rpm and indices of 1, 2 and 3.

There remains the question of the range of speed over which such a relation is likely to hold. As shown above, it must break down at very high speeds when the shoe fails to remain in contact with the damsel, but this only happens at speeds too high to be of practical interest. It is also likely to fail at very low speeds. There must be a threshold; an energy too low to move any grain, so there must be a lower speed limit below which the feed ceases completely. Again, observation suggests that this could only occur at speeds so low that other effects would have rendered the mill unworkable.

The Effect on the Governor Question

This law relating feed rate and speed clearly has a major effect on the situation the governor must deal with, but is not sufficient to explain its operation. The difficulty is that the governor operates on the millstones, and their behaviour is still not properly understood. Again, the current testing programme is designed to provide the information needed to gain such understanding, and the governor question must be considered again when the tests are completed.

The feed characteristic raises a further problem of timing. Whatever the effect of speed changes may be on the stones, it will have both an immediate and a delayed result. The immediate effect will be the grinding rate, and possibly a change of quality. The delayed effect will result from a change in the quantity of material between the stones. It will be delayed because of the transit time through the stones, which is likely to be about a minute. This will be complicated by changes in the feed rate, which will occur immediately but only affect grinding by the slow process of working its way through the stones. Against this, the governor acts immediately. Indeed, the lag governor anticipates, as its output contains both velocity and acceleration terms, although it is very doubtful whether this is of much significance in practice.

Flour dressers such as wire machines and bolters have a similar type of feed mechanism, and it is interesting that Mead's original patent for the governor includes its use for controlling the feed to them. However, there is no evidence that it was ever used for this purpose.

Conclusions

Despite doubts about the validity of the main assumption in this analysis, it seems clear that the feed rate is related to speed by a power law with an index which is certainly greater than one (and very probably greater than two), and which cannot exceed three.

This result must have a substantial effect on the action of the governor but is not sufficient to explain it.

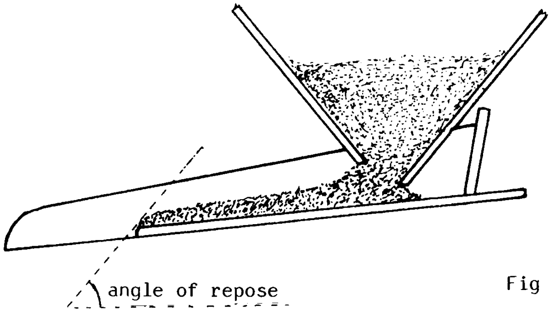

Fig 1.

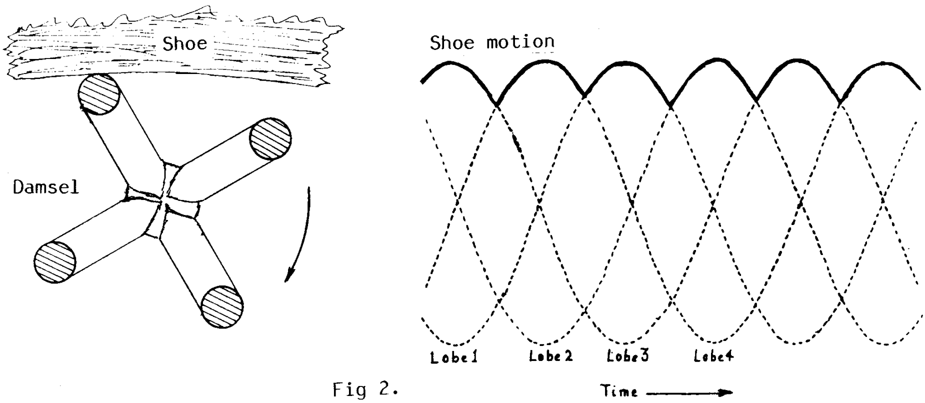

Fig 2.

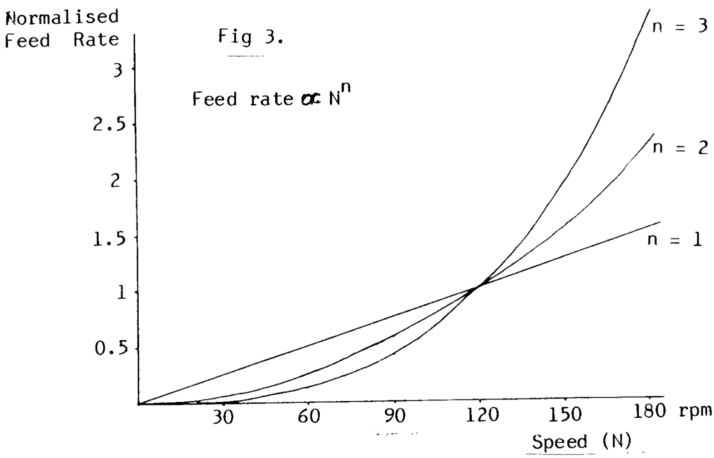

Fig 3.