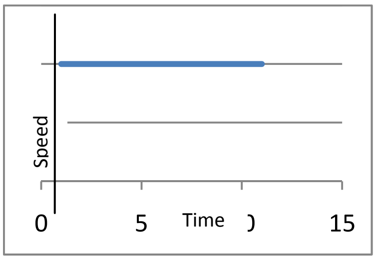
The PW3 Camshaft

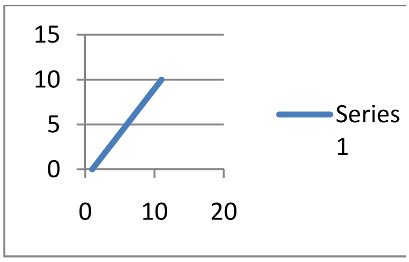
I want to tell you how to design a cam. Please don't be frightened; it certainly won't hurt and it should be fun.

I'll start with some basics from everyday life. A metre is about the same as a yard; just three inches more. A strolling speed is one metre per second. The first graph below shows a straight, horizontal line at level of 1metre per second and 10 long indicating that the stroll lasted just 10 seconds.

The second graph indicates the number of metres covered for each of the 10 seconds of the stroll.



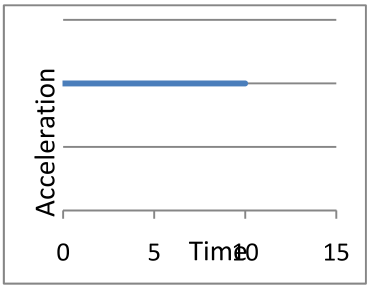
Constant speed

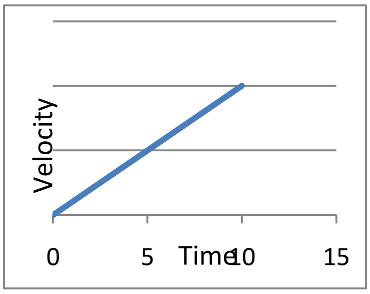


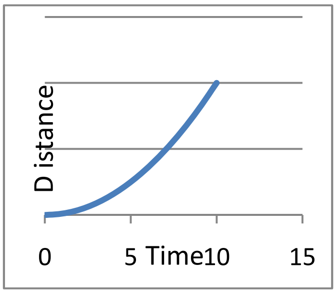
Distance at constant speed

Think now of a block of something that has a mass of 1 kilogram sitting on a really slippery surface of a table. When you push on the block with a force of 1 Newton it will be accelerated at 1 metre per second per second, i.e. 1 metre more for each second you push it.

The acceleration is represented on a graph you can see on the left below. The block will start to move and will go faster and faster and the middle graph shows how the speed of the block increases during the 10 seconds of the 1 Newton push. And the way the distance of the block increases from its starting point as the speed increases during the 10 seconds is shown on the graph on the right, below.







The force of 1 Newton is named after Isaac Nerton who put forward the rules of motion and the rules that scientists and engineers live by. In fact, perhaps without realising it, we all do. And they are amazingly simple and obvious.

First Law: Everything will stay where it is or will continue moving in a straight line unless a force pushes it to change its speed or direction.

Second Law: When a mass (called **m)** is pushed by a force (called **F)** its acceleration (called **a)** will be in the same direction as the force and the force will be directly proportional to the mass and the acceleration,
i.e. **F** = **m** x **a**.

Third Law: The pusher and the pushed feel equal and opposite and collinear forces. This means that whenever a first body exerts a force **F** on a second body, the second body exerts a force −**F** on it; the action is equal and opposite.

One of Sir Isaac's contemporaries was Robert Hooke who used to hang around in the parks ogling the girls, whereas Sir Isaac lounged around under apple trees. He was also a very clever bloke and he stated a Law that is, perhaps, even more obvious than Sir Isaac's. He said that strain, or deflection, is directly proportional to stress within the elastic limit of the material. Any force applied to anything will cause it to distort.

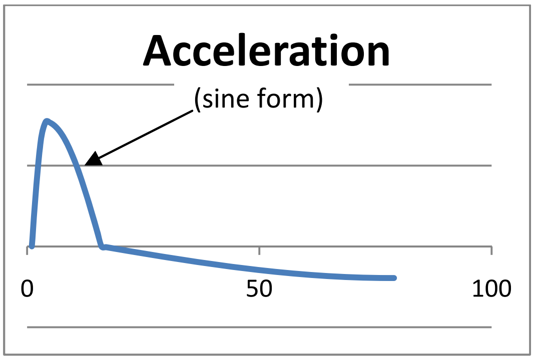
When I designed the Norton 2S, 3S and 4S cams I copied my father's work. He was Jack Williams and was race chief and Chief Development Engineer with Associated Motor Cycles (AMC). They made AJS and Matchless and other smaller motorcycles up to the mid-'60s. He had been impressed by the logic of a Mr. Bishop, who worked for British Motor

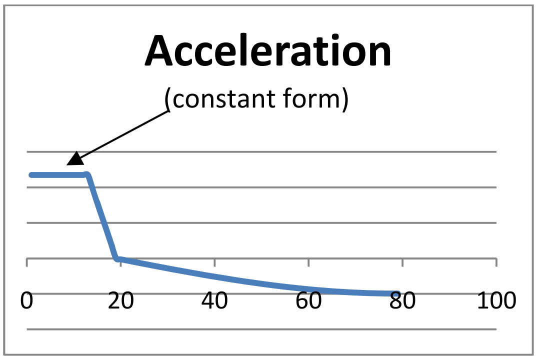
Corporation (BMC) manufacturers of Austin and Morris cars. He thought that using the mathematical sine curve was the natural way to move intake and exhaust valves up and down. The sine curve is the shape of the ripples on a pond after a stone is dropped in it and when you see a toy boat bobbing up and down as the ripples spread outward passed it the boat is being accelerated up and down sinusoidally. From a trough in the ripples the water pushes the boat upwards, it reaches a maximum upward velocity, and then slows to the peak of the wave. The reverse sequence occurs on the way back down into the trough.

Designing a cam to vary the acceleration of the valve mechanism with the sine form results in a smooth changing of acceleration and a smooth transition from positive acceleration to negative acceleration. Remembering Sir Isaac's 2nd Law this causes the forces created by accelerating the masses of the valve mechanism to increase and decrease gradually with the aim of limiting noise. But particularly if designing cams for racing when noise is a small consideration it seems pointless to just change acceleration and the proportionate force gradually. The strengths of the parts in the valve mechanism are concerned only whether the stresses they feel are too great or not. A gradually increasing force and resultant stress applied to a component that doesn't exceed its strength is fine. But so is a sudden force and stress that doesn't exceed the components strength.

The sine form of acceleration is similar to a Rider A slowly opening his twist-grip throttle and gradually accelerating away from traffic lights, until eventually the front wheel aviates. Instead, Rider B twists the grip so that the front wheel comes up immediately, and he shoots ahead of Rider A. Rider A will have to go to a higher acceleration by somehow delaying the front wheel from lifting, or to keep accelerating longer to catch Rider B.

I chose to follow the example of Rider B, (also following Cosworth training) in my design for the PW3 cam. I figured that a lower but sustained period of constant acceleration was better than a period of gradually increasing and then decreasing acceleration which has a much higher peak value. Again remembering Sir Isaac's 2nd Law, the higher the acceleration the higher the force will be and, consequently, the higher the stresses in the push-rod, rocker, rocker spindle, the valve itself and all areas of contact. More importantly, as Mr. Hooke prophesised, the higher force in the push-rod and rocker, the more they will distort, behaving as high rate springs. I calculated the maximum force that occurred in real life caused by the 3S Norton cam. We applied the same force on a cam follower engaged with the push-rod and rocker pushing against a fixed valve tip all assembled in a standard Norton Commando cylinder head and barrel and measured the distortion. The cam follower surface moved 0.013 inches (0.33mm) so I decided with the PW3 cam to apply much less acceleration on the valve train but to apply it immediately with no variation until ramping it down as the speed approached maximum.

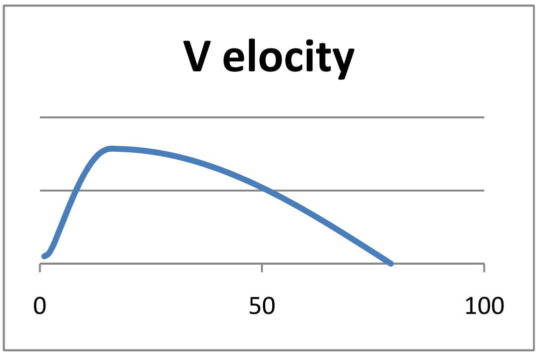


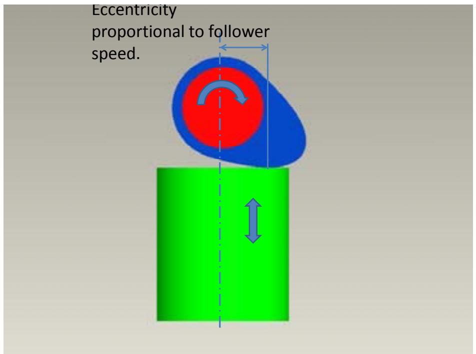


Having decided on the basic design policy of how to apply forces there are some constraints and decisions still to be made.

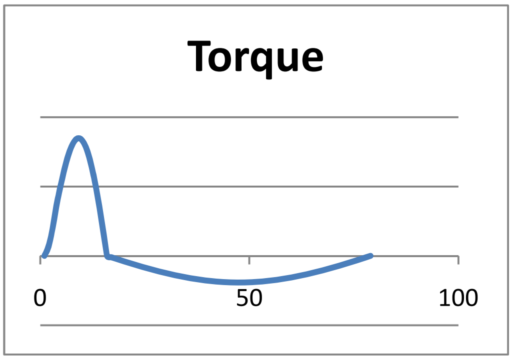
The contact point of the cam sweeps across the face of the follower as the cam rotates. The maximum follower's speed, and that of the rest of the valve train mechanism, is limited primarily by the physical width of the cam follower. In the picture on the right, below, the point of contact of the curvature of the cam with the flat follower is very near the edge. The faster the cam rotates the faster the contact point will push the follower downwards The distance of the point from the centre line is the eccentricity and for obvious reasons we don't want to design the cam for it to go over the edge..

We might be able to increase the size of the follower to allow the shape of the cam to give a greater speed but like those bike riders A and B who would have to brake harder to stop from a higher speed to stop at a particular point, we would have to make the cam with greater deceleration towards full lift. Then we would also have to make a spring that is strong enough to do the deceleration; and the curvature of the nose of the cam might become too pointed and wear out because of being overstresse

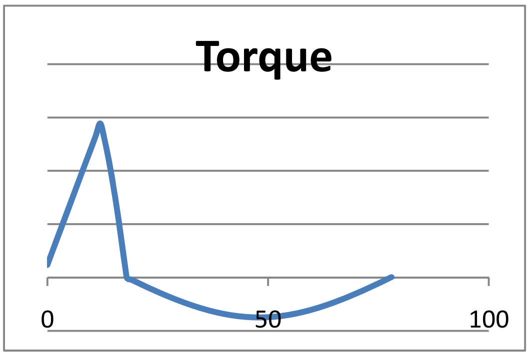




Another disadvantage of acceleration of a sinusoidal form is that the torque on the camshaft required for the cam to accelerate a valve from its seat can be destructive because a characteristic of the sine function is that the velocity, too, will vary sinusoidally or rather cosinusoidally. Cam torque varies as the product of the acceleration and the velocity resulting in very high cam drive torque which caused failure of my father's 'works' AJS 7R on two important occasions. It is very sudden, short duration, but an intense, high value 'stab torque'.



Stab torque 3S cam



Stab torque PW3 cam

The low opening acceleration of PW3 cam avoids this as well as keeping down the forces in the valve train mechanism. The push-rods and rocker, etc. are not caused to deflect (high rate springs) as much as previously. The valves of the John Player Norton using my 3S, 4S or 5S cams used to start to go out of control of the cams (floating) at around 6,600 rpm (remarkable that peak power was at 7,200 rpm). There was no point in letting the engine rev beyond 7,500 rpm. But a Norton 750cc twin can be buzzed happily and effectively to 8,000 rpm with the PW3. The valves don't float until 7500 rpm.

There are many more aspects of design to look at; the shaping of the clearance (quietening ramp) is one. And I have shown the cam follower here as having a flat face and moving up and down in a straight line (as in a cylinder) but there are radius faced followers and oscillating "finger" and rocker followers, too. Cams are fascinating!

But the two main benefits of the PW3 are more power and more torque.

The power is increased because the valves open more quickly than other cams allow and allow more air into the combustion chamber. There is more torque because the inlet valves close earlier than other cams allow so that that greater amount of air is trapped and burnt effectively.

The front wheel of the John Player Norton was only lifted when being put in the van. A Norton 750 with a PW3 camshaft can lift the front wheel in the first two gears!

And normally lubricated the PW3 won't wear out because it's made of the material that modern camshafts should be made of, chill-hardened cast iron.

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