SHAFTS against roots

Thesis & Antithesis continues to look into the new components used by the KF, and to which karters will have to get used to. After the exhaust valve and ignition, this time we will take a look at the counter shaft, evaluated by two exceptional experts: Carlo Boscolo and Umberto Merlin.

Report: Daniele Leone

It may seem a paradox, and yet the need of a balancing shaft - counter shaft – is required by the chassis and not the engine!
Although it isn't the only solution, the countershaft represents a system that is necessary to get rid of a problem caused by a bigger displacement volume, that is, more vibration. The principle is easy: put an opposing rotating mass to that of the piston mass so that vibration caused by inertial forces, less than 25% (according to CIK-FIA regulations), is reduced.
Using a counter shaft on the new KF engines meets the approval of all the experts. The different opinions among the countershaft upholders are more in techniques, some say mass directly on gears and some say set apart.
What has the chassis got to do with it then? Iame and Rotax experience have taught a lot, especially experience deriving from the Leopard. In fact, according to Carlo Boscolo, it was important to avoid the problems suffered by chassis mounting Leopard engines – 125cc KF forerunner, with clutch and battery but no countershaft – often subject to permanent crises due to frequent spindle cracking. For Umberto Merlin too, it would be absurd to make KF engines without a system for reducing vibrations. And yet, he takes on a completely different technical route from most manufacturers – he puts the rotating mass directly on gears – and it seems to be particularly successful in the class that Merlin is mostly interested in, the KF3, and shows that they've made their score.

Carlo Boscolo – Birel Motorsport's technical manager
The need of a countershaft came at the same time as the decision to make KF engines. The 100 had reached its limits: it was necessary however, to maintain the same level of performance. That's why we had to develop an engine that was capable of guaranteeing a lot of power but at lower revs. The equation was to increase displacement volume so as to give a greater show.
Turning less, the engine suffers les stress but the problem then is having more rotating mass because of the greater displacement volume. These are the reasons behind the use of of a countershaft.

Why don't vibrations create difficulties for 125cc gear class engines?

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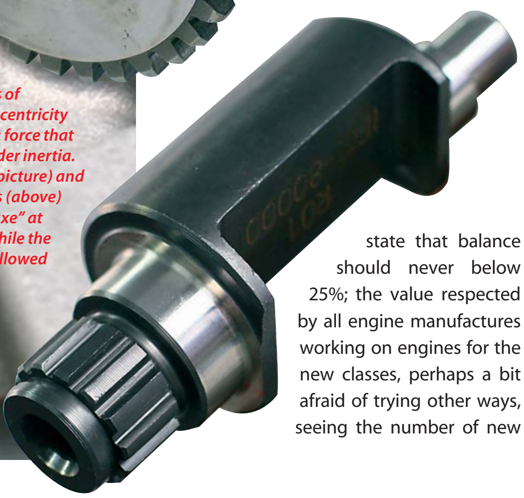
“Axe” in the engine

The balancing counter-shaft is just one of the components that characterise the new 125 KF engines, and perhaps it is one of the components that we know least about, as it is situated inside the timing case, man many don’t even know what it is for. So, let’s see what it is and what it’s for.

Report: Marco Natoli

For the Cik/Fia the KF project had to have a good dose of user friendliness: things that would make the new engines more pleasant and easier to run, for example, electric start and automatic clutch; things that together would do away with acrobatic starts and give driver absolute autonomy in this sense. We don’t want to start off any comments or controversy regarding applying these solutions also for the KF2 and KF3 classes, which have been set up with the express desire that all basic classes should use the same engines as those used for the Open and International championships. The balancing shaft, whose job it is to reduce order 1 inertial forces, hence vibration and with this increase drivers’ comfort also comes in this picture. Regulations state that balance should never below 25%; the value respected by all engine manufactures working on engines for the new classes, perhaps a bit afraid of trying other ways, seeing the number of new devices that had to be set but also aware that a bigger percentage would have developed more inertia that had to be moved, and this would have given back accumulated energy, just like in a flywheel and improved the engine’s pull.



Some examples of how to make eccentricity that produces a force that balances 1st order inertia. In the PCR (big picture) and add in TM gears (above) with another “axe” at opposite end while the Parilla has a hollowed out shaft.

What’s it like

It is an axis with an eccentric mass on it. The mass is either machined or applied. You have a gear driven by a driving shaft that turns at the same speed but in the opposite direction; that’s why it’s called counter-shaft, besides the more orthodox name “balancing shaft”. Therefore, gears have the same number of teeth as its partner.
There are many ways of finding eccentric mass, which at times, can be made up of more than one concentration (or absence) of material. Vortex gas made rather an original one. It is in three parts, a small shaft (circular section without its own eccentricity) and 2 eccentric masses keyed to ends, one of which by a key, the same one on which the gear that the driving shaft turns, is placed and then locked by a nut screwed on the end of thread. Inside the eccentric masses there are 2 bearings (this is another original thing), one is spherical another roller. The advantage is in having made the eccentric mass independent (homologated) from the relative shaft that may even be changed. Besides, this sort of solution has been dictated by the compactness of the RAV, which has a vertical reed pack and the eccentric mass that practically turn at its side in the front lower part of the timing case. The other type foresees gears that are made heavier by circular sections obtained through machining (practically there are no bores , the circular part is complete) and just one bearing. This is a simple and compact solution commonly used.

At Tm they've orientated their development programme in keeping mass concentrated by mounting mass which is separate from gears

To tell it all, vibrations don't only create risks for the engine, but they are even more harmful for the chassis. With the Leopard, one of the first TaG engines made in unsuspected times, the chassis usually used to split, especially near the spindles. This doesn't happen with the gear class 125cc, because the gears allow a different weight distribution and with it a better balance. Besides, the gear ratios allow the engine to turn from 8000 to 13000 revs and keeping the speed within the 5000 revs. Instead, the Leopard used to connect at 8000 revs and pulling up to 16000, making the most of a 8000revs range... can you imagine the strain!

Among the engines that have been homologated, there are two different solutions: countershaft with mass on gears and those with mass set apart. Which solution is right?

-Merlin and Pcr deserve to be complimented: the simplify of the gears and gear countershaft go well together with the KF3, where power is reduced and the carburettors limited to 20mm, so you need to reduce any problems concerning friction, just like Merlin and Pcr have done.

In any case, I'm sure that at Tm, our partner, Birel, have done a good job, which is also for the higher classes. As the countershaft turns at 180° respect to the position of the piston, it is aimed to zero inertia and with it any vibrations. The solution with mass on the gears allows for a closer position of the piston, but not a perfect positioning because it is lateral compared to the rotation axis. This rouses a twisting moment and therefore a fault in balance. The ideal position is that used by Rotax, which requires bigger gears though. Being inspired by Rotax and Yamaha motorcycling engines, at Tm they've orientated their choice in maintaining mass concentrated, placing the countershaft under the exhaust and standing apart from, say, the solution used by Vortex, conceptually similar, but positioned under the reed pack.

Umberto Merlin – Merlin Racing

For us, there are just two solutions: to recognise most factories and follow Rotax' example – with countershaft set apart – or make gears that already have a rotating mass to oppose driving shaft. Then we realised that both we and Pcr were the only ones to apply this last guideline.

Seeing the results, does your solution work?

Our Xtr mounts a balancing countershaft with rotating mass on gears: a simple solution especially considering the requirements of the KF£, on which we're counting. In fact, our solution is particularly good for working at low revs, and we mustn't forget that the KF3 is the class, which is limited to 14000 revs.

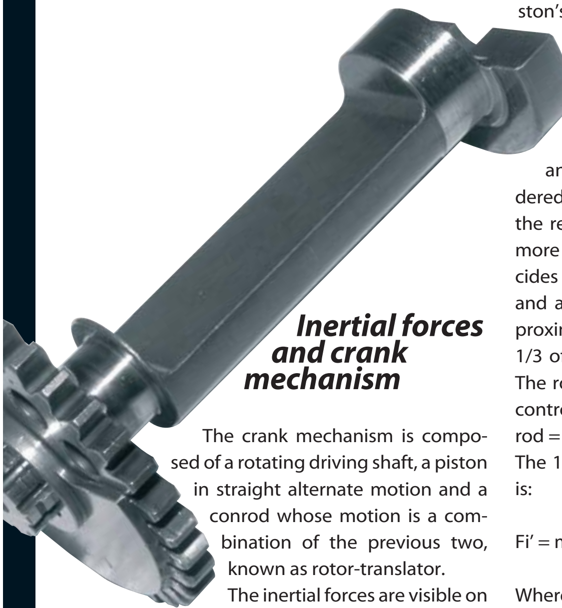
Although you are just at the initial races, can you see the time difference respect to others?

Honestly, the balancing countershaft isn't a determining factor as far as the time factor is concerned. Its job is concentrated on balancing the engine and therefore indirectly, overall engine performance. Widening opinion, its job is to do away with vibrations, the countershaft is important for the entire chassis/engine system, giving improved stability in set up.

And technically speaking?

We had much more freedom on paper because the space taken up by the countershaft with mass on gears is very little. But apart from the programming phase, another great advantage is the mechanical phase: it takes less time to disassemble the engine, and we all know how precious time is in races.

The new MRC uses a balancing countershaft with rotating mass on gears: a simple solution mainly developed for the KF3



Vortex (left) has decided on solution with 2 removable masses, separated by the axis. Maxter (below) has made a double operation: made the rotating axis lighter on one side and at the same time made the gears eccentrically and on opposite end.

Inertial forces and crank mechanism

The crank mechanism is composed of a rotating driving shaft, a piston in straight alternate motion and a conrod whose motion is a combination of the previous two, known as rotor-translator.

The inertial forces are visible on parts that endure any variation of translation speed, and this is the case of the piston complete with pin, locks and segments; its speed is never constant, it varies in continuation. It has to bear the inertial force that reaches maximum point at the dead points, where it is in maximum acceleration (speed changes sign).

The shaft turns and it is subject to centrifugal force.

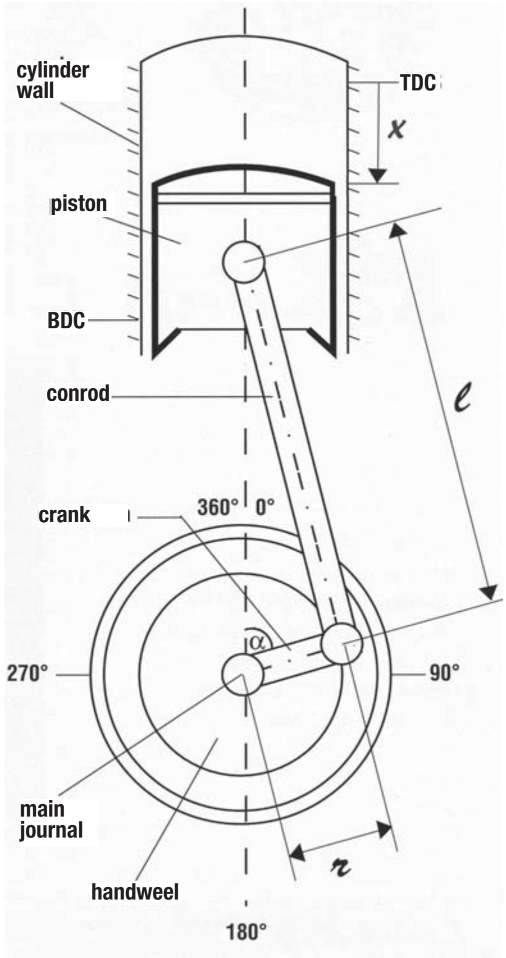
What about the conrod? Its exceptional prerogative is to change the piston's straight alternate movement into the shaft's purely rotation movement and is underlined by its motion, a combination of both and which is very difficult to describe analytically. In any case, part of its mass is considered to be in alternate motion and the rest in rotation movement. To be more precise, the big end (and coincides with reality) has straight motion and about 2/3 of the rod's mass (approximation); the sum of both is about 1/3 of the whole mass of the conrod. The rotational movement of the shaft controls the other 2/3 (head and 1/3 of rod = 2/3 of total mass).

The 1st order inertial force expression is:

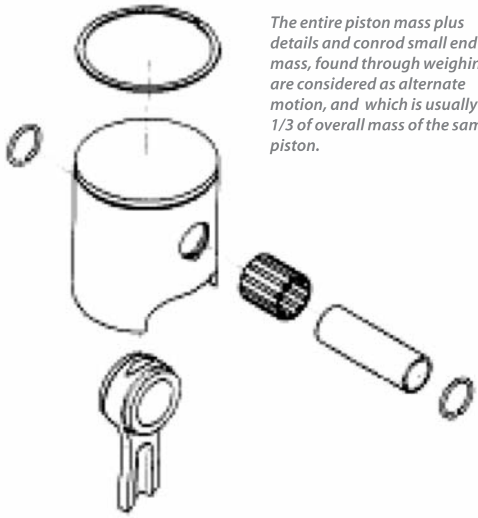
$$Fi' = m\omega^2 r\cos\alpha$$

Where, with reference to the outline,

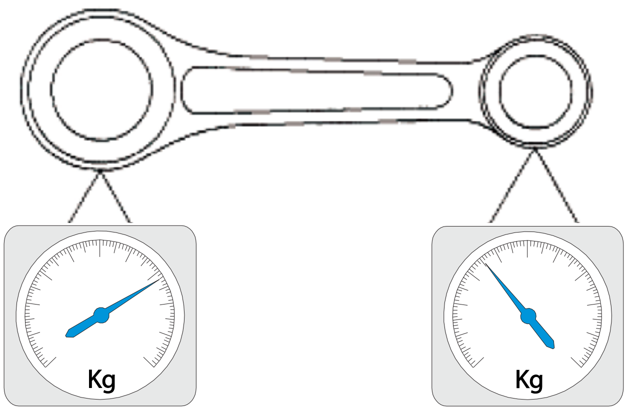
m: mass in alternate motion (piston and a third of the conrod),
r: shaft length (half of the stroke)
ω: angular speed in radiant/seconds (ω =2πn/60 where n is in revs/min)
α: general angle that individuates crank's position (hence driving shaft)

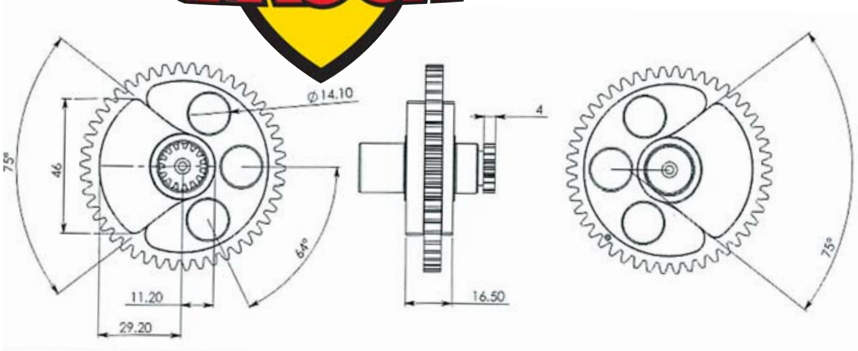


Sketch of the crank mechanism of a single-cylinder

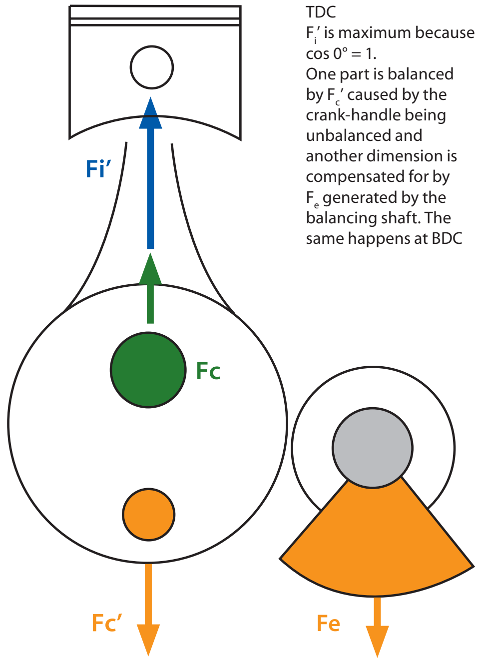


The entire piston mass plus details and conrod small end mass, found through weighing, are considered as alternate motion, and which is usually 1/3 of overall mass of the same piston.

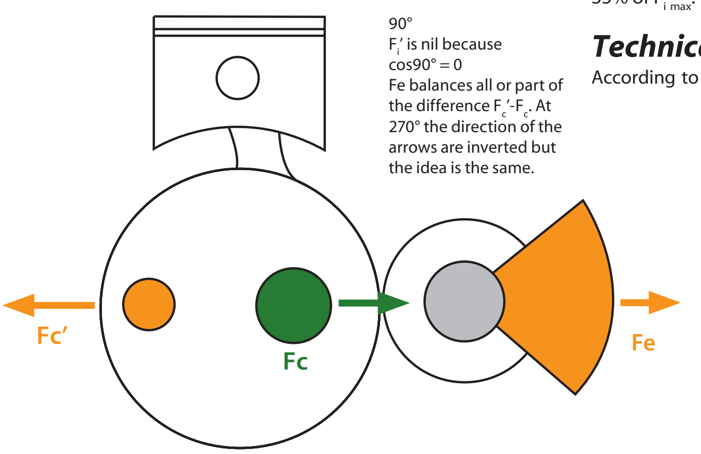




On the heavy homologation fiche for the new KF engines, on CAD sketches you have cam sizes (above the Windfire's) with which you can work out the balancing momentum.
Further to the right, the MRC XTR's eccentric gear



TDC
F_i' is maximum because cos 0° = 1.
One part is balanced by F_c' caused by the crank-handle being unbalanced and another dimension is compensated for by F_e generated by the balancing shaft. The same happens at BDC



90°
F_i' is nil because cos90° = 0
Fe balances all or part of the difference F_c'-F_c. At 270° the direction of the arrows are inverted but the idea is the same.

at a certain point (at TDC it's 0° at BDC 180°)
cos α: cosine trigonometric function of the angle α (at TDC and at BDC = 1 maximum value)

You soon see that the 1st order inertial force is directly proportional to mass, at speed and piston stroke.

Balancing

In the single cylinder you could balance the maximum inertial force, the force that is evident at the dead centres, simply by inserting some mass in the driving shaft's ball crank handle so that the centrifugal force that they stir is equal to $F'_{i\,max}$, that is $m\omega^2 r$. But in the other positions this force would be too much respect to Fi' which becomes nil when the crank is at 90° and 270° respect to vertical (90° cos and 270° is = 0). In this position it would have an undesired horizontal stress (backwards and forwards). Therefore you balance a part of $F'_{i\,max}$, usually 30-35% if the cylinder is vertical. In fact, horizontally it gives a force that is only equal to 30-35% of $F'_{i\,max}$.

Technical regulations

According to technical regulations, balancing crankshaft should balance 25 % minimum, but of what? Of mass in alternate motion, independently of the manufacturer's choice of balancing crank mechanism as we have mentioned, that is, unbalance the shaft's ball crank handle, getting a percentage of balance that at this point we'll say "intrinsic", to its description. Here, it doesn't say anything, it doesn't look into the matter, and it just says that you must balance 25% of mass in alternate motion with a counter-rotating shaft.
To find alternate motion mass, it uses the same criterion that we mentioned earlier on. Practically speaking, sports marshals work as described below.
All mass in straight alternate motion is accurately weighed: piston, segments, pin and locks.
Weight the conrod. To do so, rest the 2 ends on two different scales or one end at a time on the same scale, making sure that the conrod body is lying horizontally. Note down the weight and add the weight of the entire piston to that of the big end. The countershaft has to balance 25% of this mass and the calculus is simple.
The moments of the 2 forces must be even; one is given by mass weight in alternate motion times its maximum arm, that is crank r (half of the stroke) when it's 90° respect to vertical (α = 90°, cos

α = 1); another moment is produced by the countershaft's eccentric weight times the distance from its rotation mass, and the value must be equal to 25% of the first. While in the first case you can easily find what weight is by using the method mentioned, in the second you have to rely, that is until you start having doubts, on what the manufacturers say about the eccentric weight and its distance from the rotation axis. However, there must always be a CAD drawing of the element on the homologation fiche and from this it is possible to find the balancing moment through accurate sizes and density of the material (steel) always set according to regulations, 7.8

g/cm3. You might find that some fiche don't have any sizes on them to help sports marshals carry out this calculation

Balance between 25% of the 1st order inertial force momentum and that of the eccentric weight is:

m_a g r 25/100 = me g d

where

m_a: crank mass in alternate motion
r: conrod length

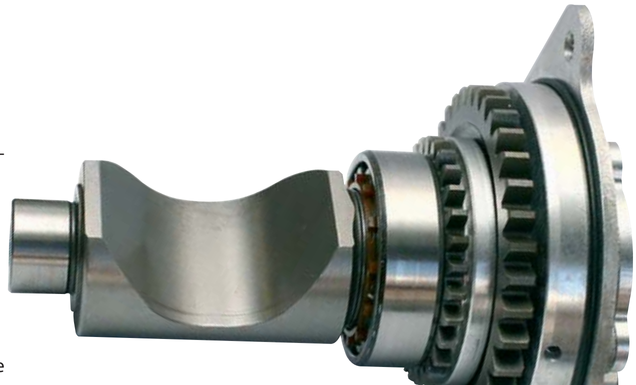
me: eccentric mass on countershaft
d: eccentric mass distance from its rotation axis
g; acceleration gravity

to make things easier:

m_a r 25/100 = me d

For sports marshals ma and r can be easily verified a mentioned above, while for me and d you have to rely on the manufacturer.

You must be able to easily disassemble the countershaft and check presence and function simply by looking.



Villa and Lenzo have decided to use a similar solution to Iame's, with shaft hollowed out at the side; but the lengths are different for between the VKR (above) and the LKE (centre). Comer (bottom) instead has decided on two separate axes mounted at the end of the shaft.

Why a countershaft?

We have given a political reason at the start. Now let's try to see the technical reasons, seeing as the balancing function of the 1st order inertial force could have been simply done by balancing the shaft's ball crank handle. The reason for its existence could be found in the fact that it turns in the opposite direction respect to the driving shaft and being quite distinct form this.

At TDC, say, F_i' faces upwards, like the Fc centrifugal force of the crank mechanism that turns. Being unbalanced the ball crank handles creates a downward F_c' centrifugal force that only balances 30-35% of F_i'. At the side though we have the eccentric mass and this too is downwards and unbalances F_i' a bit; the opposite happens at BDC. And not only. Near the other 2 critical points, 90° and 270° (here F_i' is nil), being counter-rotating, its centrifugal force compensates (all or in part) the F_c' that creates horizontal stress.

Therefore, balance is "set" in the same direction, as its eccentric mass has to be positioned below when the piston is at TDC. The rest happens automatically because it is counter-rotating. We must add that the eccentric balancing force is at a certain distance from the driving shaft, compared to which it creates a momentum, and to eliminate it you ought to mount 2 subsidiary small shafts (instead of one) that both turn in the same direction but contrary to the driving shaft, each having half the required eccentric mass, whose momentum balances out. This though, is even more complex as a solution and besides it not worth it , considering the simplicity of the engine and thinking that it is destined for "racing" and not to a top car. Don't forget that what we have said so far about balancing a single cylinder only refers to 1st order inertial forces. 2nd order inertial forcer are less, about ¼, they have a double frequency, but they usually are overlooked in this sort of application.