Turning point in the creation of racing engines: structural parts made by laser sintering

ABSTRACT

Besides the numerous non-structural parts made by selective laser sintering that can be found in the Ilmor engine, the 2007 innovation project is a real turning point in the creation of racing engines! If this exceptional R&D should reveal itself to be winning even under extended running conditions, the future of the engine and frame production will have the green light towards really new and interesting delivery times, costs and performances. The new challenge is the optimisation of the CAMSHAFT COVER for the newest Ilmor engine, that should race in the 2007 MotoGP. The CAMSHAFT COVER is the structural part that supports the bearing of the camshaft (camshafts seats, the camshaft usually runs at more or less 19000 rpm), directly applied on the 4 stroke 800cc engine head. Inside there is also the lubricant oil.
Average working temperature: 130-140 °C.
The improvements this project will achieve are as follows:

1) Lightness (of the engine head cover. Being on top of the engine, each saved gram means better rideability of the bike, allowing to lower the centre of mass)
2) Reliability
3) Fast modifications and production (the possibility to change during the season some features of the part)

FULL PAPER

Besides the numerous non-structural parts made by Windform XT that can be found in the Ilmor engine, the 2007 innovation project is about a real turning point in the creation of racing engines! If this exceptional R&D should reveal itself to be winning even under extended running conditions, the future of the engine and frame production will have the green light towards really new and interesting delivery times, costs and performances.

Motorcycling engine camshaft cover

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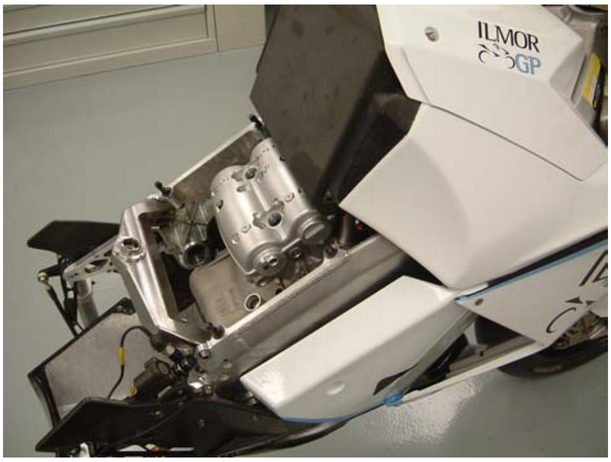


The improvements this project will achieve are as follows:

1) **Lightness** (of the engine head cover. Being on top of the engine, each saved gram means better rideability of the bike, allowing to lower the centre of mass) **(- 31%)**
2) **Reliability**
3) **Fast modifications and production** (the possibility to change during the season some features of the part)

The most critical aspects of the motorcycle engine camshaft cover, are the **centring and maintenance of its position on the seats and the oil capacity**. Its performance is fundamental as far as the reduction of the weight, time and cost is concerned. This part is usually CNC machined or cast and then machined: its limit is the unquestionably long lead time.

The aim is to extend plastic laser sintering technology and application to new components combining it with traditional metals, which enables us to create a composite sintering metal (as can be considered a composite the "reinforced concrete"). The advantages of this new innovative method are principally the versatility and the speed, while its limits could be the mechanical characteristics of plastic that are inferior to some metallic alloys or to laminated carbon. Studying every different application, the aim is to broaden its use.
Obviously, the cost is always taken into consideration and the aim is to introduce this technique where possible and when it can lead to a cost, weight and production time reduction, which consequently enables a further advantage on the production costs.

Goal

During the meeting with Ilmor, the aims of the project were defined as follows: ***rationalising and improving the performance of the engine camshaft cover.***

Different steps were necessary throughout the process:

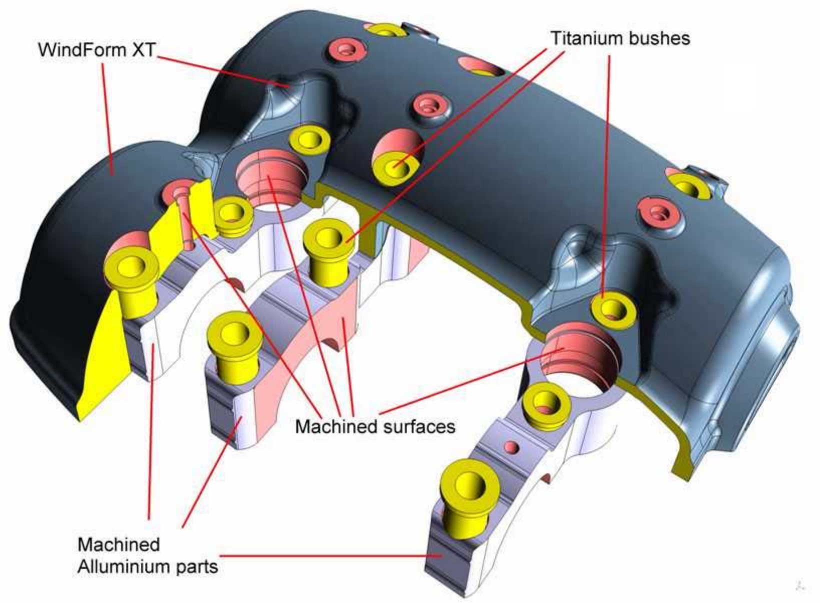
1. Deleting, as far as possible, the metallic material machining, replacing all the parts that have no strict mechanic matching and less stress with plastic parts.
2. Limiting the weight but keeping the intrinsic structural qualities of the design.
3. Rationalising the machined areas using almost exclusively the wire cut process and minimizing the milling.

After some intermediate steps, in order to value the main limits of the job, a result has been reached and then optimised to guarantee the best compromise between the three starting points.

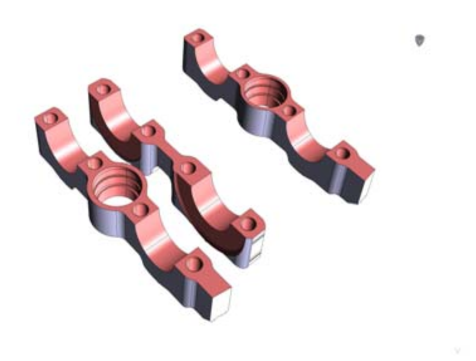
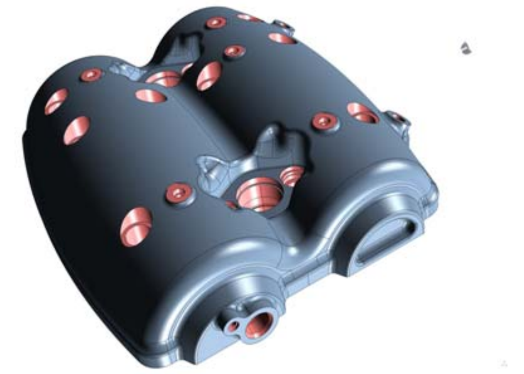
The design, and also the process engineering of the parts have been deeply analysed and changed, keeping in mind the working conditions and the stress that it has to bear, as the camshaft runs usually at more or less 19000 rpm.

Result

The result is a **composite part where the different materials will have a specific function or structural competence**.



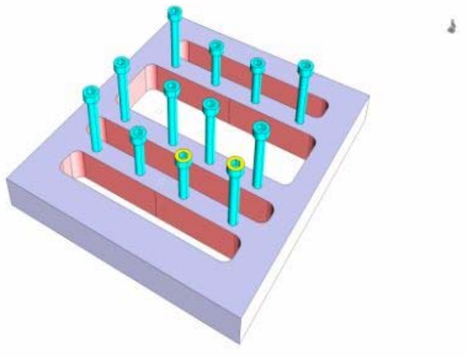
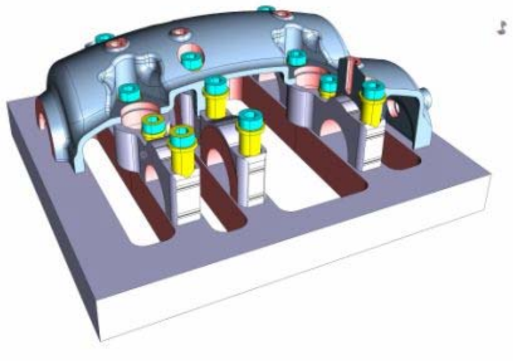
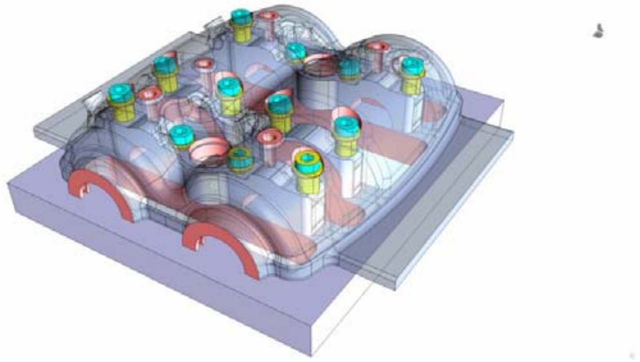
Around **a main-frame in** metal-ceramic matrix (**aluminium MMC**), a **shell made by carbon fibre filled resin** (**Windform XT**), was created. The shell is therefore, the result of powder sintering using high performing CRP developed material, directly from a mathematic model in a few hours. The main areas of the part (camshaft seats) are made by a series of simple cutting and welding processes, while the prototype shell has the complex shape. In fact, being made by selective laser sintering, any complex shape can be obtained without undercut problems (a typical limit of CNC machining process) or supports (a typical limit of other Rapid Prototyping technologies).

	
main-frame in metal-ceramic matrix (Aluminium MMC)	shell made by carbon fibre filled resin (Windform XT)

The seats of the shaft were therefore realised in MMC: "Metal Matrix Composites" to offer further weight savings, increased stiffness and exceptional strength and fatigue resistance. The industry standard is AMC225XE. An aluminium alloy AA2124 reinforced with silicon carbide particles, typically 2-3 micron, 25%

by volume. The material is versatile. It can be CNC machined directly from "HIPped" billets, forged or formed by using extrusion or rolling techniques. Like all materials which include silicon carbide it is also highly abrasive and requires the use of PCD tooling. It can be wire cut and CRP use two Charmilles machines to profile billets and forgings.

Then everything is assembled on a specific "**jig**" (mask) with the use of high performing adhesives developed for strong aerospace applications, with maximum confidentiality on their composition and properties.

	
	everything is assembled on a specific "**jig**" with the use of high performing adhesives

To better understand why the manufacturing of this composite element, with a part realised in Windform XT and another in AMC MMC, is so confidential and interesting, it's important to explain the **bonding difficulties** that all technicians have to face when the two materials to bond are **aluminium and carbon**.
The classical carbon fibre and the aluminium alloys, when in contact, create a "pile", and thus "**galvanic corrosion**", especially in humid and salted environments (i.e. sporting boats). Obviously, in the

environment, there is always a certain amount of humidity and this can generate the "flowering" of the aluminium, from which cracks can start, invalidating its performance.

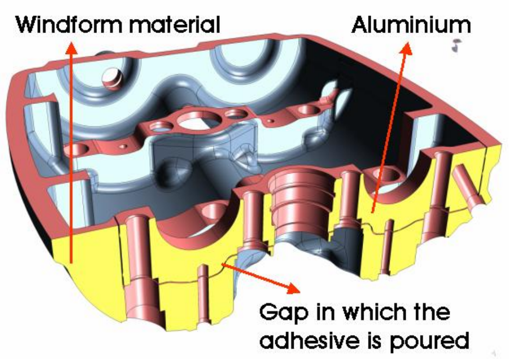
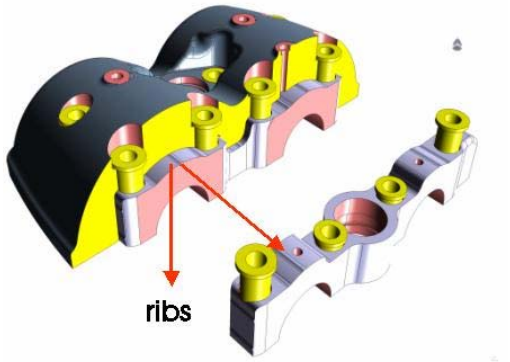
In addition, the **thermal deformations** usually make the connection nearly impossible. In fact, while the laminated carbon has a coefficient of thermal expansion (CTE) which is very low, the aluminium alloys expand much more when heated. An alloy traditionally used for hi-tech applications as the Al 2024 has a linear CTE 68 °F of 23.2 µm/m°C, which means for example that 1 meter of material, from 20 °C (about 68 °F) to 100 °C (ΔT 80 °C) suffers a deformation of about 1.85 mm (23.2 * 80= 1850 µm= 1.85 mm), while the carbon remains more or less the same. Upon analysing both of them, the carbon is the material with more stiffness and resistance. It doesn't deform itself and has the effect of "pushing" on the bonding, which can collapse and detach itself from the alloy. The adhesives used are in fact generally quite stiff.

Therefore, a solution for the galvanic corrosion could be the lamination on the metallic area first with glass fibre and then with carbon: the glass fibre acts as an interface and eliminates the contact between the two extremities of the "pile", the carbon and the aluminium.
Unfortunately, for parts working at high temperature, this solution doesn't solve the problem of the thermal dilatations. Moreover, while the process used some time ago was the carbon lamination directly on the metal part (or with glass interface), now the preferred choice is the carbon lamination on a mould. Then the metal part and the housing part are milled: components are then bonded. Between them a layer of adhesive is applied working like an insulator, but the problem at high temperature remains if the adhesive used is stiff.

Recently, in order to solve this problem, detailed research has been conducted on the adhesives for extreme applications, to maximise their elasticity thus maintaining optimal adhesion.
There are no doubts about the fact the preferred bonding remains the one between carbon and titanium alloys, where the problem of the galvanic corrosion is limited and where the coefficients of expansion are closer. The Ti 6Al4V actually has a linear CTE 68 °F of 8.6 µm/m°C: in the preceding example, for a meter with a ΔT of 80°C there is a length variation of 0.68 mm (8.6 * 80=680 µm=0.68 mm), definitely lower than for the aluminium.

The MMC AMC225xe is exactly in the middle between aluminium and titanium. It has a CTE of 15.5 µm/m°C and gives a lengthening on 1 meter with ΔT of 80 °C of 1.2 mm (15.5 * 80 = 1200=1.2 mm). With special and elastic adhesives, it is therefore possible to have fewer problems than with pure aluminium alloy.

In this specific case, the situation is enhanced: the Windform XT has in fact a high coefficient, but being the "softer" material, it does expand and deform itself, reducing the push on the bond line, while the laminated carbon does oppose itself to the aluminium pushing. As the supports were made only in MMC, and therefore stiffer and more resistant with the same weight of the aluminium alloy, the elongation difference between the two components is smaller, they are more compatible and the bonding doesn't seem to give big problems. With regard to the problem of the galvanic corrosion, as Windform XT has a strong polyamide component and less carbon, it gives smaller potential differences, when in contact with MMC, when compared to laminated carbon and therefore the problem doesn't exist anymore.

	
With special and elastic adhesives **Windform XT** and **MMC** are more compatible	The **ribs** help to: 1)Increase the glued surface 2)Set the connection between the 2 parts

In addition another 3 versions were studied, one of them with another Al alloy instead of MMC (plus Windfrom XT of course), and it seems it could work with some treatments too, but this is the latest development and there is additional confidentiality on it. MMC in fact may not work very well for cams to run against and some additional processes may be necessary.

Following this, the **engineering strength of "rapid manufacturing"** is relevant to all, if combined with a technical team that has a great materials know-how and good skills in manufacturing and engineering technologies. Within a shorter time, it allows you to develop a very high performing product, even with different evolution steps and without increasing too much the first hypothesized investments and costs.

This is the typical work method for companies coming from Formula 1: their DNA has to be different to support the best constructors and their needs. Therefore a perfect knowledge of the team needs is required even before their requests, it is important to act in a thousandth of the typical production time, there is no time to make mistakes and recover the lost time, there needs to be continuous innovation and passion. **That's why it's called the motorsport niche: only a few people can manage to keep pace with us.**

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