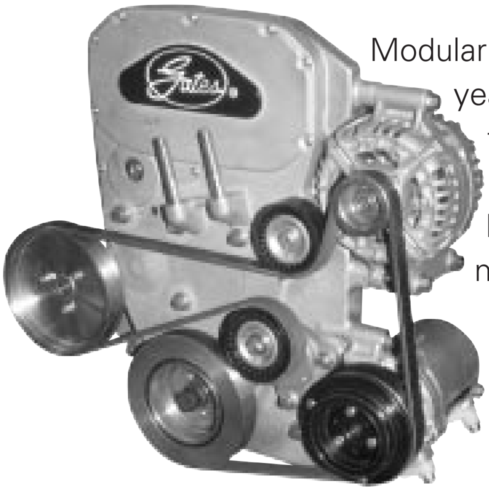
You will find the figures mentioned in this article in the German issue of MTZ 5/2005 beginning on page 376.

Ein innovatives Modul für Synchron- und Nebenaggregatsantriebe

A Innovative Module for Timing and Auxiliary Drives



Modularisation has been growing within vehicle manufacturing for several years now – Front End Modules, Corner Modules and almost the entire interior has been modularised. This trend has not been so marked in the powertrain field but opportunities do exist. The Gates Engine Module family introduces significant potential for growth in modularisation of powertrains.

By Gordon Hensley and Roger Stone

1 Introduction

The GEM idea started with a vision: the concept of a fully self-contained module that would include everything from the front face of the block forward and which could be assembled to the base engine with an absolute minimum of labour and lineside complexity. The challenge was: "How could it be done?" The GEM10 demonstration unit comprehensively answers that question. It incorporates the entire timing drive, water and oil pumps, Torsional Vibration damper and the full auxiliary drive including tensioner, alternator, PAS pump etc. **Figure 1** shows the first unit based upon an engine employing a timing belt drive, whilst **Figure 2** shows a timing chain derivative on a Vee engine.

The unit is assembled to the engine by lining up the crank pulley/oil pump bore with the crankshaft and sliding the module along the crank axis to the Front Face Of Block before tightening the shaft and structural fasteners. Note that everything is included in the module, all fasteners are captive, gaskets retained and any dustcovers a snap fit on polymeric hinges. No part, other than the module itself, has to be picked from lineside. The effect is that, even allowing for different auxiliary dress configurations, some 100-150 parts covering 50-75 part numbers are driven out of the engine plant to be replaced by only 1-3 modules.

To achieve this result, a number of challenges had to be overcome. Technical issues, such as how to retain and locate the timing drive components within the module, were just the first in a wide range of issues. There were also logistics questions– including how to "nest" the modules in delivery racks to achieve both a cost effective shipping density and a satisfactory presentation to the final assembly station. The module to engine assembly process had to be simple and utterly reliable and the value stream show genuine savings, not simply cost transfers from OE to supply base. Finally, the quality of the finished engine could not be compromised; indeed, it should be enhanced by the application of the new idea.

All these issues, and more, have been overcome during the development programme from idea to viable product.

2 Product Concept

The challenge was to achieve the vision without compromising the functional integrity of conventional arrangements. The priorities were: simple, error-proof assembly processes both for the module and for module to engine assembly, a robust transit condition for the module, the avoidance of a weight penalty and good NVH characteristics. **Figure 3** shows a module in the transit condition.

One significant benefit is that, in many cases, the module permits Gates to optimise the drive layouts, both timing and accessory. Tensioner and idlers can be located to improve the drive and positioning is not compromised by base engine architecture, for example, at the joint of two components or close to the cylinder or water jacket.

2.1 Structure

The main component is a structural, pressure die cast, aluminium housing shown in **Figure 4**. This forms the rear part of the casing for belt or gears timing drives, whereas, in the case of a chain drive, it would take the place of the chain cover and would be located "between" the timing and auxiliary drives. All other components are integrated into or mounted from this main casing. The rear casing, combined with a structural front cover, forms a clamshell or very stiff box section structure affording excellent support for the auxiliary machine mounting points. In order to maximise the effectiveness of this support, and minimise weight, tangential auxiliary mounts were chosen. This is consistent with the current trend as a stiffer mount is achieved even in conventional designs.

The design adopted uses a clearance compensating sleeve nut threaded into the bracket from the cylinder block side. A bolt is screwed into the bush from the other side until the shank binds against the (sacrificial) internal thread in the bush. This is the shipping condition, **Figure 5**. At the appropriate point in the module fitting process, the joint is made simply by turning the bolt, just as would be done for a "normal" joint. Because the internal bush thread is stiff due to interference with the bolt shank, the bush unscrews until it makes contact with the cylinder block boss and the sacrificial thread strips after applying a small pre-loading to the bracket. The bolt is then free to engage the thread in the cylinder block boss and the large flange on the bolt head clamps all the parts in the joint in compression. Note also that, by employing a reduced shank bolt, clearances and tolerances in all three planes are compensated.

1 Introduction

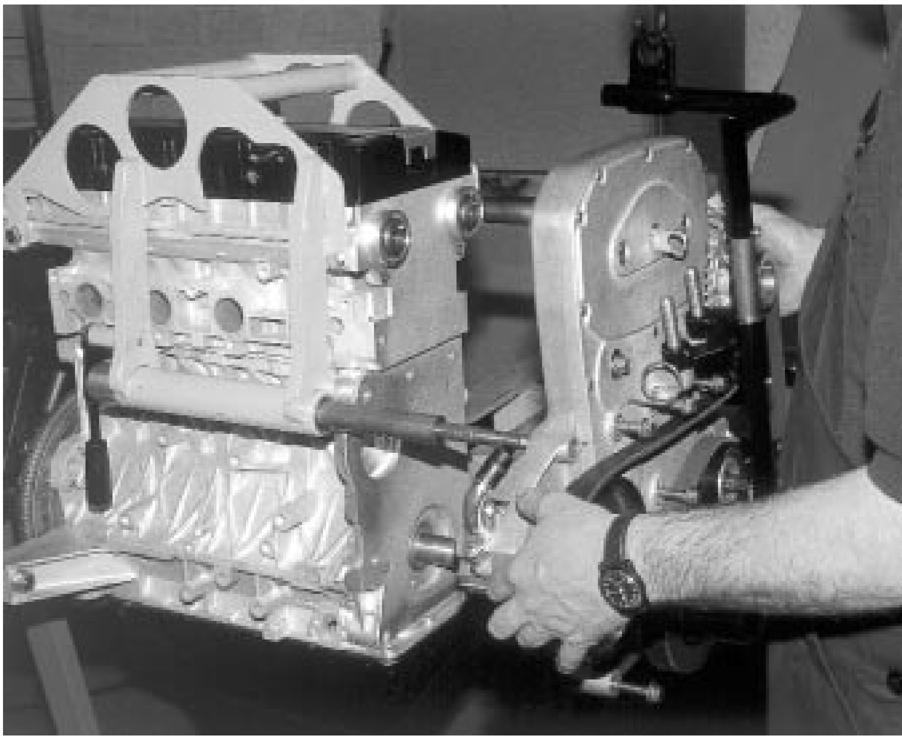


Figure 1: The first GEM10 module ready to mount to its engine

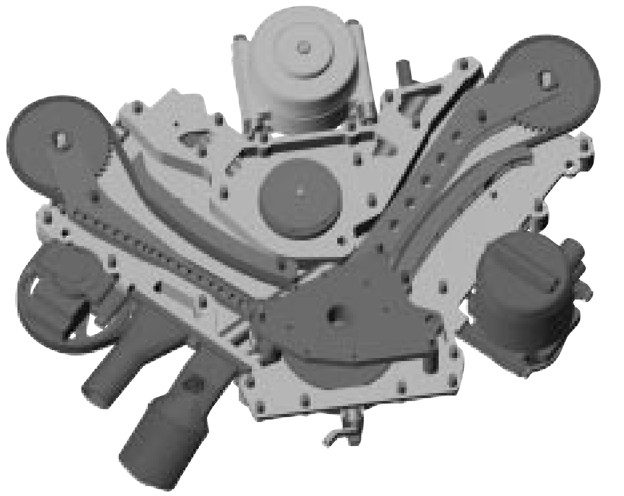


Figure 2: Study for a chain drive module (GEM12) on a Vee engine

The design appears to be unique, having many other applications – a number of which, completely unrelated to modules, are already in development.

2.2 Integration

Integration of most components did not present problems; the oil pump was fully integrated into the main casing but the water pump, for service reasons, was not. The TV damper and its bolt are retained by the cover and a plastic washer respectively. The timing belt tensioner floats in the casing until it is bolted to the cylinder block; this presents no problems but, because this tensioner is fully enclosed, the normal pre-tensioning installation procedure is not possible. Because of this, a unique "One-touch" tensioner has been developed that requires no adjustment or pre-setting and which is fired and adjusted simply by bolting it down. A section is shown in **Figure 6**.

The most difficult aspect of this part of the design was the location and retention of the cam pulleys. One solution can be seen in **Figure 7**, showing how the pulleys are located radially by means of steep matching cones in the main casing and the pulleys. The front cover restricts axial motion of the pulley so the possible positioning/orientation of the pulley centreline is constrained within a clear envelope. The pulleys are timed during module assembly and locked by a disposable plastic clip, so there is no possibility of the belt jumping a tooth while the module is in transit. Of course, it is also important to ensure that the pulleys are concentric with the camshaft axis after assembly but the conventional solution of spigot location does not lend itself to blind assembly. To address this problem dowel bolts were used for the cam pulleys. Combining this solution with a small, pilot diameter on the nose of the cam bolt also provided guaranteed correct engagement of the bolts with thread in the end of the camshafts first time, every time. The large diameter dowel hole in the cam nose provides a "target" the small, pilot diameter on the nose of the bolt cannot miss: this ensures correct engagement with the threaded hole. Tightening the bolt then engages the dowel and pulls the pulley in line with the camshaft. Simultaneously, the axial position of the camshaft end face ensures that the pulley is held clear of the cone in the housing.

3 Noise, Vibration, Harshness (NVH)

The all-aluminium construction of the first module design caused some concern that NVH may be a problem. However, careful design (internal ribbing, broken and curved surfaces) plus some FEA optimisation provided very satisfactory results. The first mode frequency actually increased by 14 Hz from what was already a very competitive level. Furthermore, radiated noise calculations showed significant reductions in, 2nd and 4th order components contributing to an overall improvement relative to the original engine.

4 Package

In all 5 studies undertaken so far, there has been no engine length penalty and in one case there was an advantage! Generally, it has also been possible to achieve a tighter package in end elevation by packing the auxiliary machines closer to the block.

5 Manufacturing

The initial manufacturing study was carried out on the basis of an arbitrary production volume of 350,000pa – typical of many new engine manufacturing facilities Subsequent work has been completed for higher and lower volumes but these will only be touched on here. Since the novel aspects of the concept pertain primarily to the assembly processes, manufacture of the base components will be omitted in this article.

5.1 Assembly Philosophy

Good manufacturing practice coupled with the obvious need to ensure maximum economic benefit drove the philosophy towards a lean manufacturing. This requires, amongst other things, right first time processes with good ergonomics combined with a clear and obvious assembly sequence. Assembly of the module itself was relatively straightforward and was designed around a conventional "power and free" platen line assembly process using the main casing as the basic building block. Assembly of the module to the engine, whilst superficially challenging given blind assembly of the timing drive and the relatively large mass of the module (over 25kg), proved surprisingly simple. In fact, two processes have been developed and simulated, the first assuming a low level of automation and the second fully automated.

The benefits to engine manufacturing operations are clear and wide-ranging from simplification of the material movement through to increased productivity through less complexity.

5.2 Module Sub-Assembly

Traditionally, engines are assembled with the crank in a horizontal plane so the timing drive assembly process is forced into the vertical plane. This means that parts frequently have to be manually aligned, assembled and even held in position while fasteners are engaged and tightened. Furthermore, some elements of the process call for the operator to stoop in order to see or assemble components at or below crankshaft level. The module, on the other hand, can be assembled in the horizontal plane, which is both ergonomically more satisfactory and also permits greater use of simple, low cost "pick and place" automation including automatic bolt feed and running, **Figure 8**. Simple features in the casing can act as error proofing devices or as locators ensuring correct placement. Integration of assembly validation by probes or vision systems into such a line is simple and low cost. There is an inherent improvement in pulley alignment over any design using brackets because the driven machines are all mounted direct to the same datum. This can be further exploited by using an automated station to finely adjust the auxiliary pulleys into perfect angular alignment and axial offset relative to the datum face thus providing a major improvement to one of the most common causes of auxiliary belt drive warranty claims – noise due to pulley misalignment.

5.3 Module to Engine Assembly

A base requirement for the assembly process is that both crank and cams can be timed and locked in position before the module is assembled to the engine – a common practice in engine assembly. Access to release the shafts must be from top or rear. It is possible to accommodate a number of types of key but the typical Woodruff key is not considered suitable because of the danger of its "riding out" of its groove during module assembly. The concept is best suited to, but does not require, the increasingly popular "keyless" assembly processes, which permit more precise valve timing to be achieved.

For the high volume solution a shuttle system was designed. In this case the operator simply loads the module onto one of a pair of shuttles while the other is in the fully automated fitting station. This solution was designed to cope with extra complexity in the form of optional VVT on the exhaust cam and two different crank to cam centre distances. The 4 derivatives were accommodated with only two modules by designing the timing drive and assembly station in such a way that the same module could be applied to either block height. This was achieved by providing common geometry on both VVT and non-VVT cam pulleys and electronically controlling the position of the cam sprocket centres as the module slides into place. A swinging idler was used to take up the disparity in timing belt length. The shuttle layout is shown in **Figure 9**, and exploded view of this module in **Figure 10**.

6 Service Implications

For field service staff the only evidence of a change is the fact that some of the bolts passing through the timing cover are bigger and longer than normal, the auxiliary and timing drives can be service exactly as they are today. A timing belt driven water pump can be accessed and replaced quite conventionally. Structural bolts placed outside the timing cover ensure that fluid sealing integrity between module and cylinder block is maintained.

7 Logistics

The first and most controversial issue is the conflict with the common practice of assembling the auxiliaries and their drive on a separate "dress line" typically associated with the relevant vehicle plant. This is not a universal practice and, in Gates view, may be associated with excessive complexity and therefore waste. There is huge disparity in practice; at one extreme there are OEMs who fit the same engine into a variety of vehicles yet produce only two auxiliary drive derivatives – base and with air-conditioning. Yet there are also examples of one base engine being fitted with dozens of different auxiliary drives. Some suggest that the GEM10 concept drives complexity upstream – Gates view is that it should more properly be seen as an opportunity to drive complexity OUT!

Another logistics issue is that of WIP. The high value of the proposed module means that it must be considered as a JIT/JIS delivery item assembled local to the customer plant. Gates is prepared to consider all potential requirements along these lines up to and including using Gates staff to fit the module to the base engines in the customer plant.

Packing density is another consideration that cannot be ignored and must be linked to lineside parts handling. However good an idea may be from other considerations, if the lineside material handling requirements are not feasible the whole idea fails. The example of a module packing proposal in **Figure 11** shows acceptable mass and space effectiveness plus acceptable conditions for lifting individual modules from the pallet. The V-engine module shown in Figure 2 could be packed in 2 opposite facing interlaced rows. The operator would work up one side then spin the pallet and work down the other – a technique already employed elsewhere.

8 Benefits

Benefits to the OE's arising from this concept are many and varied but the primary advantages can be summarised under the headings Quality, Cost, Complexity and Risk.

8.1 Quality

Dramatic alignment improvement for the auxiliary drive is most valuable. The horizontal assembly orientation with the casing as the assembly frame improves ergonomics, allows greater use of error proofing, more automation and better assembly validation. Linking automation and validation to the platen readers provides better traceability than is common for auxiliary dress facilities where opportunities to automate are more limited. Supply of validated modules will also reduce engine rework and thus deliver a further benefit.

8.2 Cost

The study showed that, at 350,000pa, the direct OE headcount saving in lineside operators was 48 heads and the absolute manpower reduction including module assembly at the supplier was 18 heads. This excludes material handling etc., which would provide an additional cost saving.

Over 400m2 of floorspace would be saved in the engine plant plus savings in any dress lines. This translates into lower cost or greater throughput as required.

savings are also made by the elimination of assembly line stations – again both at the engine plant and any dress lines. Furthermore, elimination or reduction in dress lines is elimination of duplication. The capital requirements for the module line will be significantly less than the equivalent section of an engine line.

As far as material piece cost is concerned, there is little change. Additional material in the main casing is offset by elimination of brackets and integration of other parts. This rapidly coalesces into significant savings if advantage is taken of the opportunity to reduce the number of derivatives, eliminating multiple, smaller volume brackets. In every "conversion" study so far there has been a small net weight saving – so the absolute mass of material is reduced. Obviously, to maximise cost and weight benefits the GEM concept should be an engine programme assumption from the outset.

8.3 Complexity

For an in-line DOHC petrol engine the typical engine plant parts count reduction ratio should be approximately 60:2 if air conditioning is an option. The handled parts ratio would be more like 100:2. If derivatives can be eliminated these ratios can improve yet further. Complexity is, of course, closely linked to cost and these improvements translate into savings in parts procurement, material handling, sorting, part number administration, engineering etc – the cost of complexity at OE level is difficult to quantify accurately but there is no doubt that is very significant!

8.4 Risk

Reducing complexity reduces risk and improves quality – if the requirement for a unique part is eliminated then it does not need to be engineered or validated, it does not need to be tooled or procured, it cannot be cause programme delay, be misfitted and it does not need to be maintained as a spare long after it becomes obsolete for production.

Capital risk is reduced because there is an absolute reduction in capital required and some of that requirement is transferred to the supplier.

Quality, warranty and volume risks are reduced by the ability to procure pre-validated, traceable modules for what is typically one of the bottleneck areas in engine assembly plants.

9 Conclusions

The module concept has been shown to meet or surpass all the original objectives – functionality, NVH, assembly process robustness, quality, total cost and complexity reduction. The concept provides huge benefits for the OE in terms of quality, direct/ indirect labour, capital and complexity management.

The original challenge "How can it be done?" has been answered and during concept development, solutions for timing belts, chain drives, in-line and Vee configurations, petrol and diesel layouts, SOHC and DOHC have all been covered. It is also possible and realistic to consider modules which are less ambitious and one conversion study, Figure 11, considered a "dry" module which did not incorporate oil or water pumps. A number of patent applications relating to the GEM concept have been lodged.

At the time of writing the first programme is in process and volume production is anticipated during the 2nd half of 2006. Discussions are ongoing for two other programmes and Gates looks forward to seeing a new process emerge, changing the way the engine of the future is assembled. ■