Virtual development of a crank mechanism for a MotoGP engine using latest modeling techniques

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Summary

High performance engines need to ensure a high specific power together with lightweight and reliability. The reduced time available from design to practical usage often restricts the experimental tests. The result is that numerical simulations are frequently the only step between a CAD geometry and the real part working on track.

For this reason a new version of a motorcycle engine's crankshaft has been calculated with the co-simulation between the two software Ricardo Engdyn and Valdyn. The former has been used to simulate the dynamics of cranktrain and cylinder block, the latter to simulate the drive line and timing. In fact, because of the motorcycle lay-out, the primary gear and all the transmission until the brake of the test bench need to be modelled.

The final result is the determination of the safety factors in the crankshaft's main and pin fillets. The most complete FEM stress analysis integrated in Engdyn has been used.

Keywords

Engine simulation, crankshaft durability, dynamic loads, co-simulation, FEM analysis, three-dimensional engine analysis.

Engine lay-out

The object of the simulation is the Ducati's Moto GP engine used during the 2017 season. The main technical properties are listed below:

- 4 stroke spark ignition, 1000 cm^3
- 4 cylinders in the "V" architecture, with 90° cylinder bank angle
- Desmodromic distribution, double camshaft per head and 4 valves per cylinder

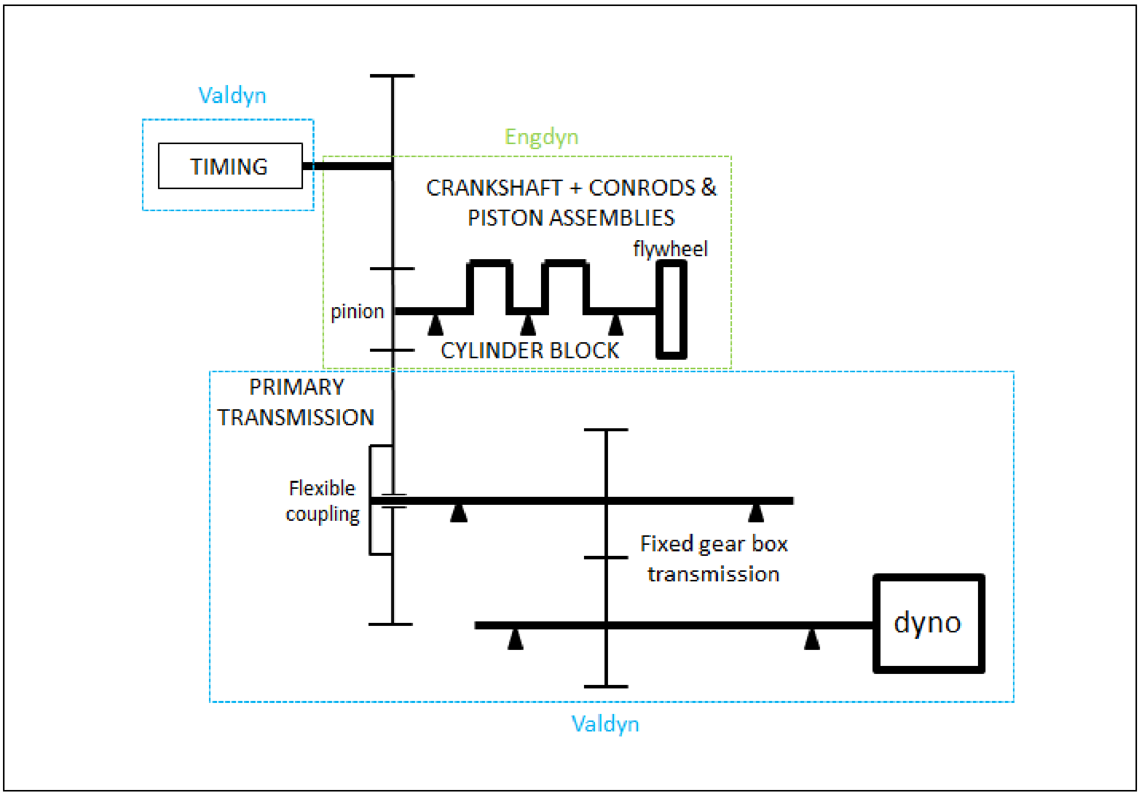
- *Figure 1: D16GP engine*

Virtual model set-up

The crankshaft dynamic of the motorcycle engine analyzed is influenced by some key aspect:

- Engine lay-out;
- Inertia and stiffness properties of the crankshaft, vibrations included;
- Inertia and stiffness properties of the cylinder block, vibrations included;
- Oil lubrication properties and cylinders pressure;
- Hydrodynamic bearings behavior;
- Pistons and piston rod dynamics;
- Flywheel dynamics;
- Max Engine speed;
- Transmission dynamics.

Some of the aspects mentioned above are common with most engines, but others require a detail focus. In particular the high revolutions reached by the Ducati motoGP engine, makes the vibration aspects (both from cranktrain and cylinder block) to be in some cases predominant. The other particular aspect, different from car's engines, is the transmission. In fact instead of having an in-line clutch, there is a pinion-primary gearing that transmits to the crankshaft both a torque and a force. Moreover the engine in the test bench has not a total decoupling from the drive line until the brake. All these aspects moved the authors to choose the full dynamic calculation offered by the Ricardo Engdyn software, coupled with the Ricardo Valdyn software. In fact the first –at the moment- does not permit to simulate the pinion's gearing with all the transmission and so the latter has been used in co-simulation. The model lay-out is illustrated in the figure below.



- *Figure 2: model lay-out*

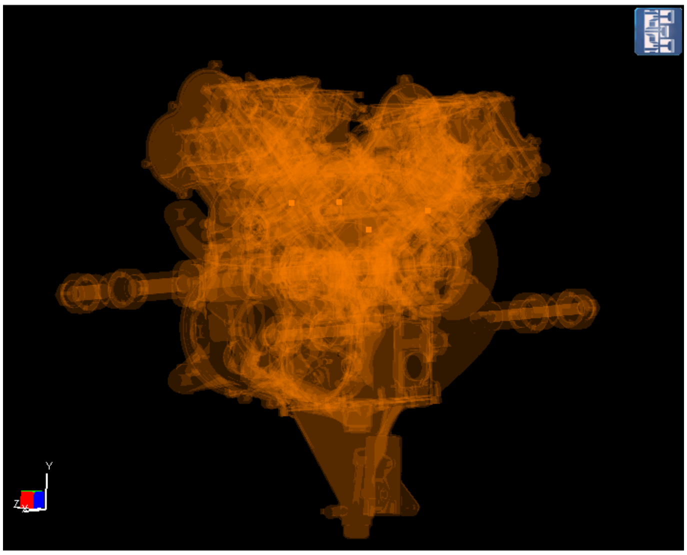
The purpose of the paper is not to explain all the steps towards the setup of the model -most of them are standard and well explained in [1] and [2]- so only the relevant features will be described next. Moreover, because of calculations time required by the Engdyn\Valdyn co-simulation, a preliminary investigation with different crankshaft geometries has been done through a simplified FEM model. A couple of geometries has been tested with the complete Engdyn\Valdyn model besides the standard crankshaft.

Engdyn set-up

The crankshaft and the cylinder block have been defined as dynamic. In particular in both cases a mesh discretization of the geometries has been used with the software Ansys, R.16.2. The cranktrain includes: the crankshaft, the pinion and the flywheel whereas the cylinder block includes: carters, heads, covers and the frame adopted in the test bench. A component mode synthesis of the first 50th modes has been done for the latter.

Three mechanical links have been inserted in correspondence of the pinion's node to interact with Valdyn. In particular angular position and displacements perpendicular to the crankshaft axis of rotation are sent to Valdyn that gives in turn to Engdyn torsional moment and forces.

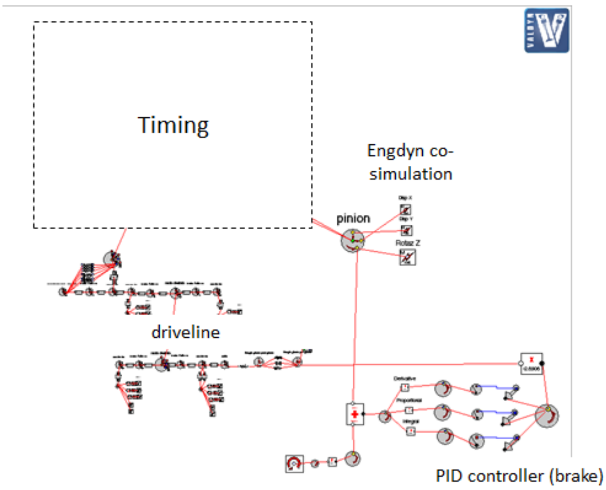
The cylinder block is bonded to the ground via some elastomeric mounts. Several mechanical links have been inserted to exchange loads derived from the timing and driveline bearings –calculated in the Valdyn model- besides the classical loads coming from main bearings, pistons and combustions. The aim is to represent a complete cylinder block loading.



- *Figure 3: Engdyn model*

Valdyn set-up

The dynamics of the driveline and timing has been modeled in a quite detailed model, until the brake for the first and the camshafts for the latter. In fact these aspects influence the crankshaft's results, as experienced from preliminary evaluations with a simpler Engdyn dynamic model without the Valdyn co-simulation or with a less detailed Valdyn model co-simulating with Engdyn.



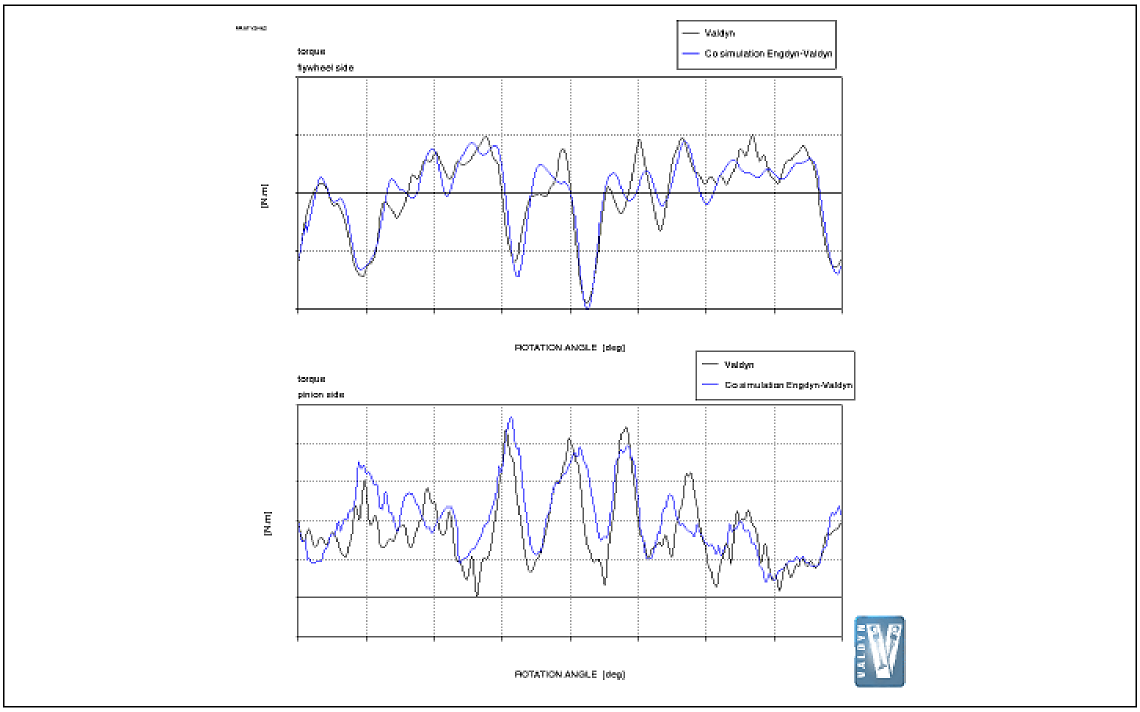
- *Figure 4: Valdyn model*

A PID controller has been adopted to avoid wind-up problems deriving from lash and low stiffness components (in particular the brake's elastomeric joint) present in the model. The model is completed with several links to Engdyn placed in correspondence of the timing and driveline bearings to transmit both forces and moments to the Engdyn model.

Model validation

Some classical checks has been done through a kinetostatic model and FEM modal analysis through Ansys Mechanical.

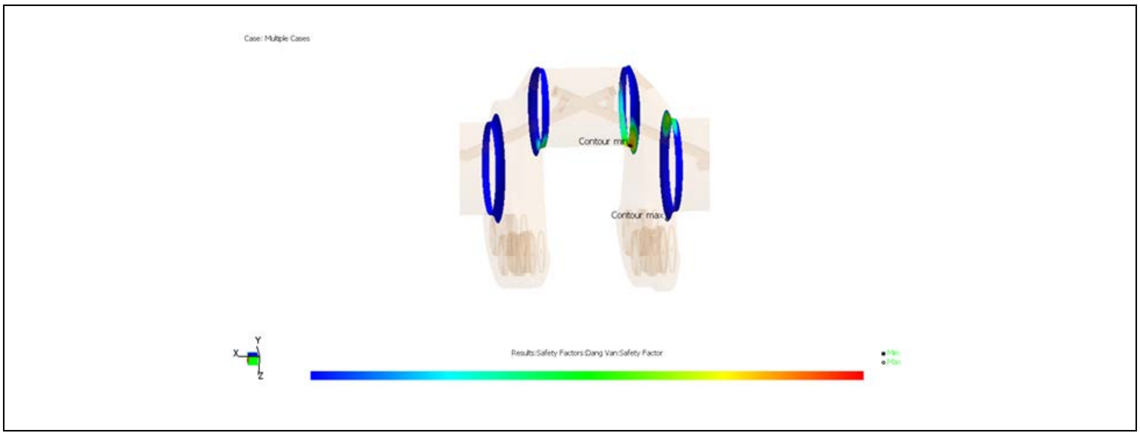
A deeper validation of the Engdyn model has been done mainly through a numerical comparison with another virtual engine model historically used in Ducati Corse. The reason is that there were not enough time to do an experimental measures campaign with the engine simulated. The historical model was instead gauged in the past, especially as for as damping is concerned.



- *Figure 4:results comparison*

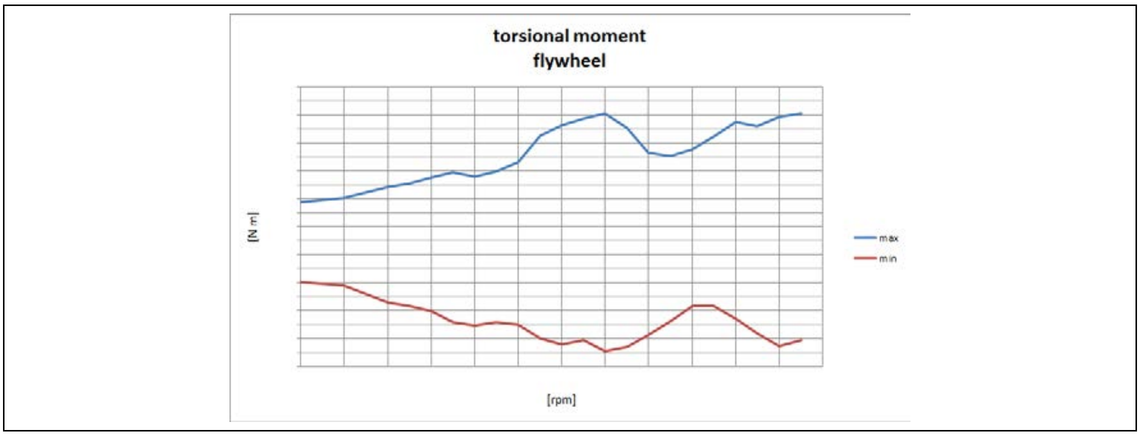
Results

The final goal of the activity is to calculate the safety factors in the main and pin journals fillets of the crankshaft. To do this the most accurate tool was adopted: FEM analysis integrated in the Ricardo software. The mesh has been done through the Ansys Mechanical software and for the mechanical properties the metallographic laboratory of Ducati Corse has been involved.



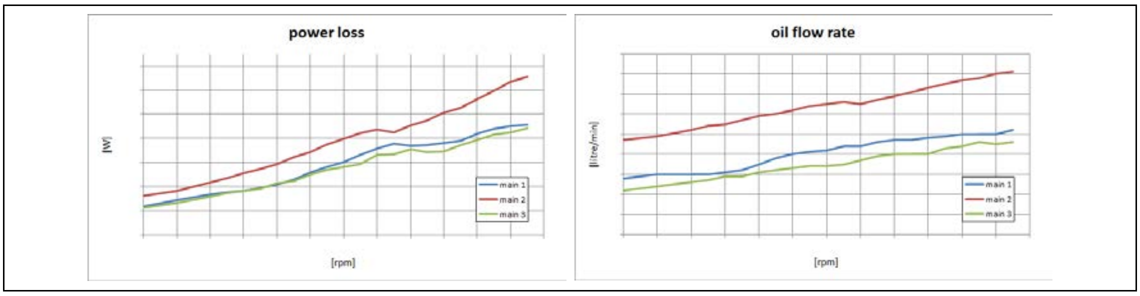
- *Figure 5:safety factors in some of the crankshaft's fillets*

Besides the final result mentioned above a huge amount of data can be extracted with the dynamic model, included hardly measurable outputs. In addition some quantities like torsional and bending moments in some key areas of the crankshaft have been extracted to generate the boundary conditions of some other FEM analysis (flywheel durability for example).



- *Figure 6:torsional moment at the flywheel side*

Bearings' power loss and oil flow rate have been taken into account primarily to compare the results obtained by the CFD calculations done in Ducati Corse and secondly to do some considerations about frictions' reduction. In order to reduce calculation times a simple mobility model has been adopted.



- *Figure 7:some bearing outputs*

A complete sweep of engine speeds with the co-simulation takes about 18 hours to complete, plus post process calculations.

Future developments

During the construction of the model some areas have been left to be quite simple. The reasons were mainly the time available and time calculations. Future developments will explore in more detail:

- Model validation with experimental data: direct experimental measures in the engine simulated.
- A more detailed description of the connecting rod and pistons (flexible FEM models).
- Some detailed calculations focused on the bearings with a elastohydrodynamic model. In this particular case a simpler model of the transmission will be used after testing the expected little effects on the bearings' results.
- A FEM analysis of the cylinder block using all the loads calculated by the model (including timing and drive-line bearings) and thermal loads, with the aim of obtain also for this component safety factors and do optimization of the component.

Conclusions

A full dynamic model has been adopted to evaluate the complex dynamic behavior of the crankshaft, cranktrain and timing. The little time available to project, calculate and test a new version of the crankshaft adopted in the Ducati MotoGP engine, together with understanding complex engine dynamic behaviors, were the most influential inputs to create a new engine dynamic model. It contains all the peculiar characteristics of the real engine, though some of them are still represented in a quite simple way. The first results obtained compared with other virtual simulations and simpler models have given a good representation of the system and so the FEM safety factors calculation in the critical crankshaft fillets have been adopted to evaluate the fatigue durability of the component. Next developments will evaluate other specific aspects, thanks to the wide model capabilities.

References

[1] Engdyn User Manual, version 2016.2, November 2016

[2] Valdyn User Manual, version 2016.2, November 2016