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Virtual Design and Simulation in two-stroke marine Engine Development

08 Basic Research & Advanced Engineering

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This paper has been presented and published on the occasion of the 28th CIMAC World Congress 2016 in Helsinki. The CIMAC Congress is held every three years, each time in a different member country.
The Congress programme centres around the presentation of Technical papers on engine research and development, application engineering on the original equipment side and engine operation and maintenance on the end-user side. The topics of the 2016 event covered Product Development of gas and diesel engines, Fuel Injection, Turbochargers, Components & Tribology, Controls & Automation, Exhaust Gas Aftertreatment, Basic Research & Advanced Engineering, System Integration & Optimization, Fuels & Lubricants, as well as Users' Aspects for marine and land-based applications.

ABSTRACT

Today various applications in the area of computer aided engineering (CAE) offer extensive possibilities for a structured design and development approach. More than ever there is a strong demand for seamless project execution across various disciplines both on- and offshore. In addition, competition forces companies active in product development to continuously rationalise their time-to-market. In order to be most efficient with design and development of new products it is not enough to have the right engineering software applications in place, it is rather a question of how these tools are integrated in the corresponding environment and how structured is the approach for uniform application by all parties involved.

This paper aims at providing an insight into the approach of Winterthur Gas & Diesel Ltd. how design and development of a modern two-stroke marine engine is carried out with focus on the actual engineering tools and methods landscape.

Looking at the two-stroke marine engine from the design and development point of view, it is a complex product which involves several systems and subsystems consisting of various assemblies and components. Depending on the type of system the characteristics are different in terms of technical requirements, specification, function, validation, execution and operation. On top of that, there is the license model which asks for a specific set-up in order to comply with the need to dispatch information from the engine designer to the engine builder which are nowadays different companies located in different countries. Within this heterogeneous environment and considering all the conditions imposed by the product, the appropriate engineering tools landscape needs to be flexible and integrated, both at the same time.

In order to learn about the engineering approach specific expert areas involved in the engineering process will be closer looked at to showcase the way of working within the execution project phase from concept to detailed design with different types of deliverables for each execution stage. This is in particular

• Development of diagrams to specify system layouts
• Conceptual design
• Concept validation
• Detailed design
• Preparation of technical documentation (drawings, specifications, manuals)

With examples from the engineering process in the two-stroke context on the one hand and the applied engineering tools on the other, the target is to draw a picture of an efficient engineering approach for two-stroke marine engine development in Switzerland for ships operating all over the world.

INTRODUCTION

The use of specific software applications for product development has been well accepted in various industries. When thinking of the engineering part for product development there is in most cases a tool landscape in place which supports the process from early requirements definition up to product release. The efficiency of this process is highly depending on the setup and way of working for each single step.

In the context of two-stroke marine engine development this landscape is influenced by specific conditions of this particular industry. As in other industries the engineering process starts with a detailed requirements definition, whereas the product assembly and release process – in form of a type approval test (TAT) – is taking place at an engine builder under a licensee contract.

With this particular conditions the release and dispatch of documentation from the licenser to the licensee marks an important milestone in the product development process for two-stroke marine engines and asks for a set-up which allows full transparency and traceability for release of deliverables and revision management.

Considering a two-stroke marine engine it has to be acknowledged that it is a complex product with elements and systems from different worlds of engineering. There is the mechanical part with components such as bedplate, A-frame, cylinder block, cylinder liner on the one hand and the plant engineering part with piping systems, steelwork and electrical systems on the other. The challenge is to combine the content of both worlds into one consistent product. On top of that all different technical disciplines with their specific demands need to be considered throughout the entire development process. Information from different sources and in different formats has to be composed and consolidated.

Last but not least seeing the engine as a functional unit within the environment of a ship, the hull design, the engine room, auxiliary equipment such as supply pumps, filters, strainers and tanks define another area of requirements which need to be reflected throughout the development process and in the product documentation.

How to cope best with all these requirements and resulting challenges and to translate this into a homogenous and efficient engineering approach including targets for improvement is the subject of this paper.

DEVELOPMENT OF SYSTEM LAYOUT

SYSTEM DEFINITION

In two-stroke engine engineering the development process starts with the Engine Control Diagram (ECD). This diagram shows an overview of how the different engine systems are supposed to work together. Information base for the ECD is the engine specification.

Inputs needed:

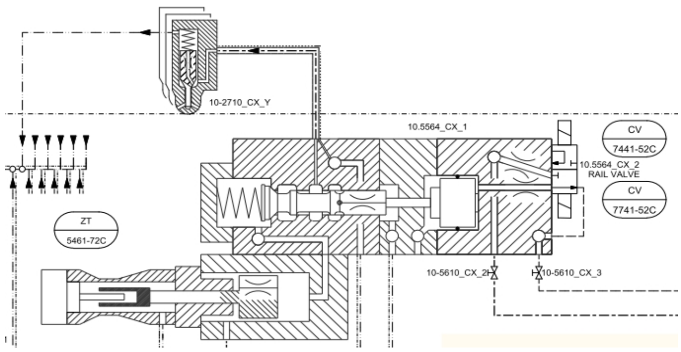
Possible cylinder number configurations, type of crankshaft (single piece or two piece), amount of turbo chargers, fuel pumps, servo oil pumps, injectors and engine control system and defined subsystems deliver the required input in this stage of development.

Tools needed:

For the preparation of the ECD the software tool Comos is used which is specified as an object oriented engineering tool. The basic idea is that all information is stored in an object and depending on the diagram type used, it changes its shape (P&ID, electric diagram, wiring diagram). The information available in this phase of development is stored in the object and can be used downstream of the development process. If at any time the information has to be changed, a centralized storage for the value is available and the change will take effect on all existing diagrams.

Activities:

Based on the information above an ECD will be developed. The decisions taken in advance regarding which technologies will be applied define whether the design of a certain subsystem can be re-used or has to be newly developed. The ECD shows how the different subsystems are connected to each other by media and function. For newly developed systems sketches from concept development are used for the representation of the subsystem in the ECD.



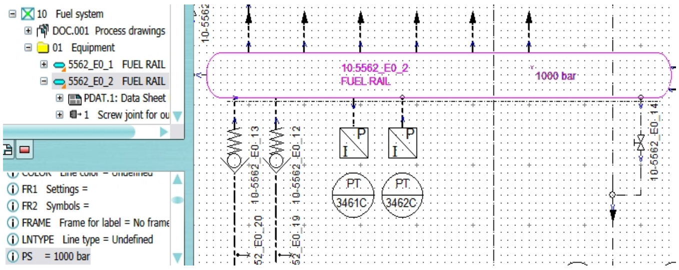
Picture 1: Mix of mechanical cross section, Std. Symbols, Pipe routings, Sensor Signals and Actuator inputs

Key systems are shown as cross section extracts where the mechanical function is illustrated (Picture 1). The most important alarm sensors, control and safety systems are defined and its conceptual positions are visualized in the diagram. System boarders are defined towards the vessel plant.

Outputs:

After formal approval a document (pdf- format) is generated which will be stored in the PLM system Teamcenter. Later on, the ECD document will be also used by Classification Societies, since it gives a technical overview in a schematic layout how the engine is supposed to work.

Attributes from specific objects which have been defined during the development of the ECD are now available for following development processes.



Picture 2: Object, Name of Object, Representation on ECD and Object Attribute (Pressure)

DETERMINATION OF FLOW REQUIREMENTS

In this phase the media flow in the different Piping System is calculated and pipe sizes are defined. Following systems have to be considered: Cylinder Cooling Water, Scavenge Cooling Water, System Oil (Servo Oil System, Main Bearing, Piston Cooling Oil, Thrust Bearing, Gearwheel, Turbocharger, Crankshaft Damper, Axial Detuner and Crosshead Lubrication), Cylinder Lubrication, Starting Air, Fuel and the Gas System, if available. The approach of calculating the pipe flows and sizes depends on the system.

Inputs needed:

The flow rates of systems such as cylinder and scavenge cooling water, fuel systems and cylinder lubrication have been calculated by the assigned specialists. In those cases the pipe sizes need to be calculated based on the flow rates available from the General Technical Data tool (GTD) which is an in house development. Parts of the oil system are split into multiple groups and specialists in the piping team take the lead to collect the information and calculate flow rate and pipe sizes of the whole oil system. The rough pipe schematics of the different subsystems need to be defined at this stage.

Tools needed:

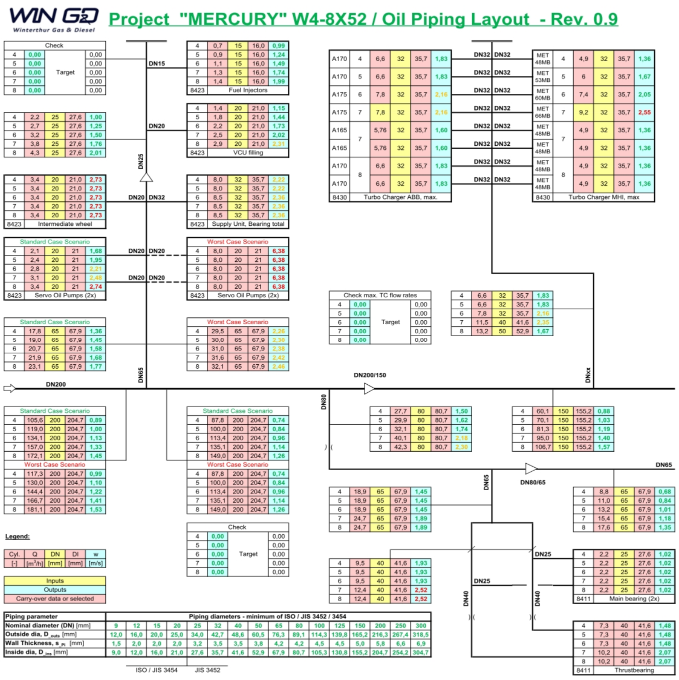
An excel document is available to gather all information. Calculated flow rate and chosen pipe diameter will give the flow velocity as a result. On the first sheet all the consumers with required flow quantities are listed. On the second sheet this information is visualized in a schematic layout.

Activities:

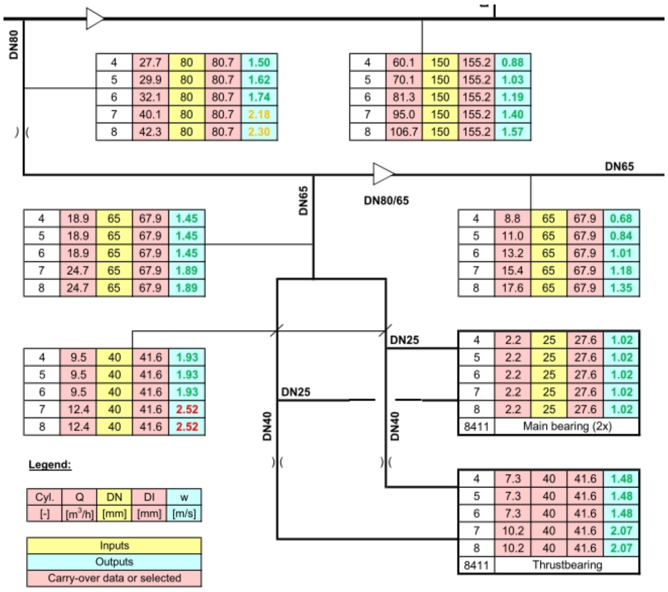
From the manufacturing point of view (customer perspective), the pipe diameter has to be defined as small as possible. On the other hand, a pipe diameter being too small would result in high flow velocities and as a consequence in pressure losses. This would increase the operational costs for the vessel. The target is to find a solution allowing different configurations of an engine (number of cylinders) and to have as many commonalities as possible. The final solution has to fit for the majority of the configurations. It is advisable to have not more than two different pipe sizes in the end.

Outputs:

For the outputs the focus is on the flow velocities rather than on potential pressure losses. As this would need additional inputs (such as pipe length, number of bends and other pipe elements) which are not available at this stage of development. From experience it is known which velocities are economical for different pipe sizes. Based on the velocities the economical index is shown with different colours (Picture 3 and 4). That way critical speed can be quickly identified and evaluated if acceptable.



Picture 3: Partial overview of oil flow



Picture 4: Detail with Main Bearing and Thrust bearing consumers

DEVELOPMENT OF PIPING DIAGRAMS

After preparing all information needed from the piping system side including pipe diameter, rough piping layout, position and size of components such as valves, orifices and reducers, the next step is to summarize all this information in one document. This document should be clear and easy to read in order to provide a quick access to required data for further use in conceptual and even more in detail design. In the past, two different diagrams have been used for that with partly identical data. There has been a piping diagram from the piping department and the control and auxiliary diagram from the automation department with all signals such as sensors, actuators and local instruments shown on top of another piping diagram. Documents which did not differ too much, however prepared by two different departments. In order to reduce the risk of information mismatch and for economic reasons, it has been decided to combine both documents.

Inputs needed:

The calculations of the flows and the system overview are the base for developing the piping and instrumentation diagram (P&ID). Additional inputs come from the automation department with a list of all signal numbers and the information where they are connected.

Tools needed:

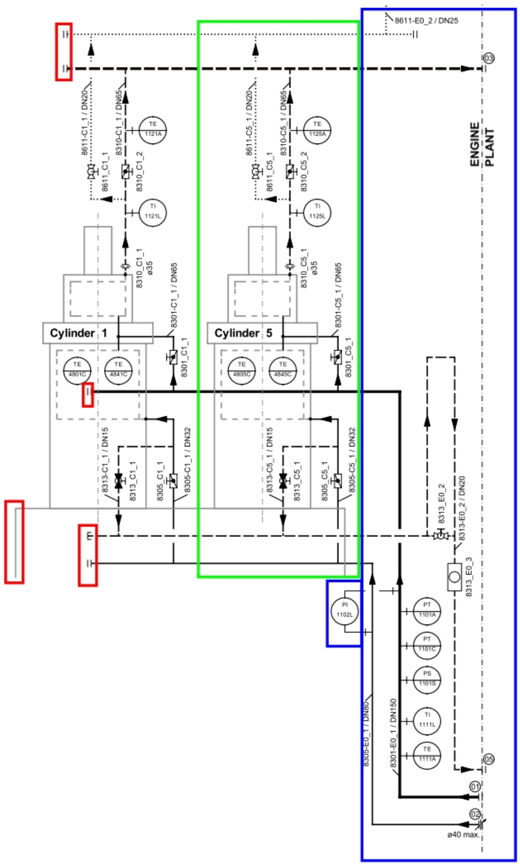
Comos is also used to create piping diagrams. Now the benefit of having used Comos for the ECD pays off. Already defined objects can now be reused and simply placed on the document. Attributes such as pressure levels already defined in the object are now also available for the piping diagram. Modifications on attributes or added information, e.g. flow rates have to be made only in one place of the corresponding object. Opening the ECD the next time will trigger an automated modification without interaction of the user.

Activities:

The rough idea of the piping diagram exists already from the calculations. Now the task is to bring this into a proper diagram.

Some devices on the engine offer several configuration options. This leads into a huge amount of possible engine configurations which would result in the same amount of pipe diagrams. To reduce the amount of work a modularized structure has been built. Most important are the amount of cylinders and different turbo charger configurations. Diagrams are then built based on this different modules.

For the different cylinder numbers of an engine type the piping diagram can be split in 3 parts: Driving end, middle part and free end. Driving end and free end are the same on all engines. The middle part depends on the amount of cylinders. The approach for the middle part is to draw one cylinder and copy paste the total number of cylinders on a document.



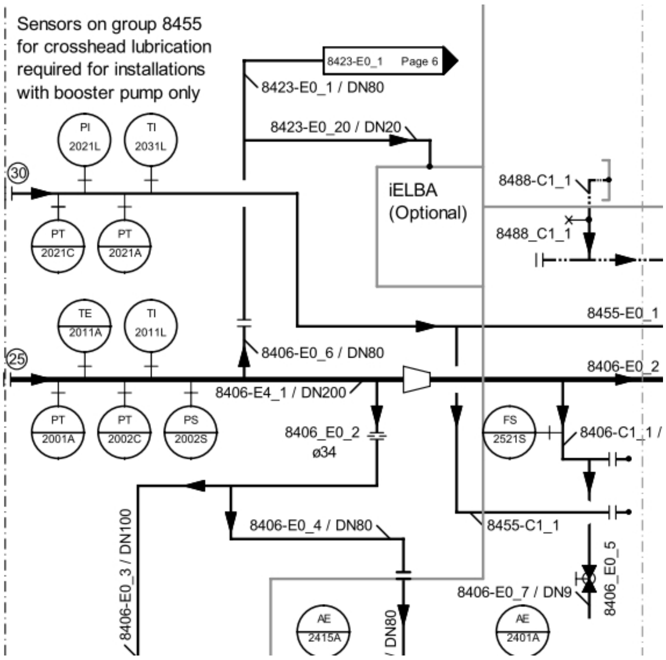
Picture 5: Piping Diagram (Red: driving end part, Green: repeating cylinder part; Blue: free end part)

Different turbo charger executions are covered by different documents. This is because different numbers of turbo chargers cannot be combined in one piping diagram.

Outputs:

From Comos the data is exported to drawing documents (pdf- format) which can be approved and eventually revised. The following information is shown on the document:

- Pipe diagram of all systems
- Pipe diameter
- Object denominations
- Orifice sizes
- Signals



Picture 6: Section of Piping Diagram

CONCEPTUAL DESIGN

In the conceptual design phase the 3D modelling can be started based on the information available from previous phases. Several mechanical main design groups of the engine are already in the design process at this stage. Based on the actual design status a total assembly (TOA) can be built which includes all elements of the engine.

The design and drawing system is split in different main drawing groups. They are specified with a 4 digit code. The first digit stands for the following systems:

1 - Structure (Column, Bedplate, etc.)
2 - Combustion (Cylinder Liner, Injection Valves, Exhaust Valve, etc.)
3 - Powertrains (Crankshaft, Crosshead, Piston, Turning Gear, etc.)
4 - Control (Starting Air Valve, Control Air Supply, etc.)
5 - Injector Actuator (Rail unit, Supply unit, etc.)
6 - Scavenge (Scavenge Air Receiver, Turbocharger, etc.)
7 - Platform
8 - Piping
9 - Monitoring

Each main group is divided into sub groups. For example 8XXX for Piping contains the following subgroups:

81XX Exhaust Manifold
83XX Water System
84XX Oil System
86XX Air System
87XX Fuel System
88XX Heating
89XX Gas System

The last two digits are then consecutive numbers.

Inputs needed:

The main engine layout has to be available. This includes bedplate, column, cylinder jacket, receiver, rail unit box and combustion parts. They represent the basic outline of the engine. Together with the shipyard interface this new engine interface now defines the workspace for additional ancillary systems.

During this phase additional input is triggered by design-to-cost factors, manufacturability and serviceability.

Tools needed:

Currently the CAD system is under migration at WinGD. Until now Ideas has been used and for new projects NX is starting to take over. For 3D modelling of piping systems the NX add on Mechanical Routing has been chosen to support designers in the best possible way. As 60% of all drawings of an engine are piping and platform related, a proper tool is important for the success of an engine project in terms of timely delivery of project deliverables.

The use of the Mechanical Routing functionality asks for a careful initial build-up of component libraries according business needs. In case of WinGD, standard part catalogues are available in the form of company standards. They have been used as a basis to build specific component libraries covering all international standards being required for piping and platform design for the Asian market.

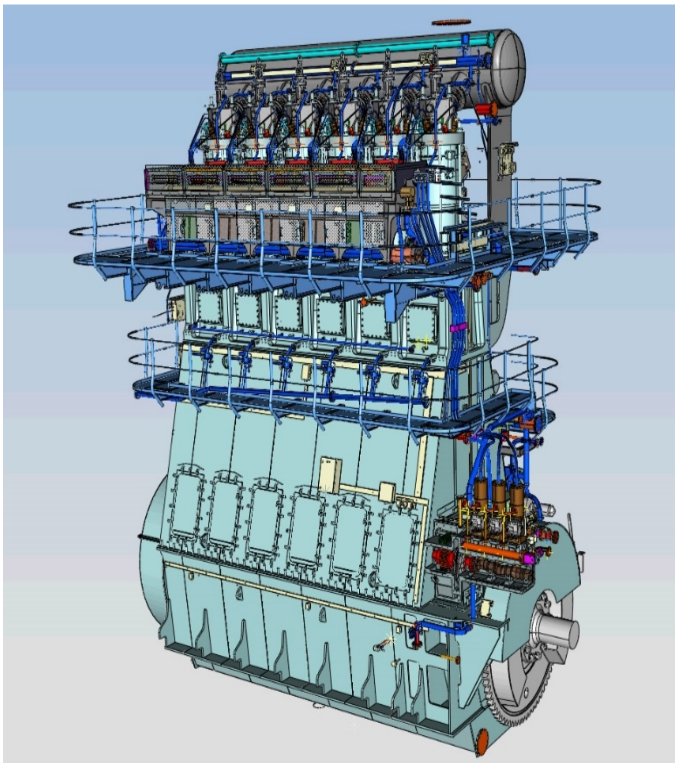
Activities:

In a first step pipes with large bore diameters are placed along the engine. Preferably they are grouped together in order to allow Licensees to build modularized pipe assemblies and mount them in packages to the engine. This allows an efficient assembly process and helps to reduce the overall assembly time of a new engine.

In a second step pipes with small bore diameters and branch pipes from the mainline to each cylinder unit are specified by a 3D layout. Now also flanges and valves are set according the piping diagram. From an industrial design point of view the target is to respect the engine outline dimensions in the best possible way in order to achieve a clean engine outline with all piping systems and steel structures for engine maintenance.

Outputs:

In the phase of conceptual design 3D layout concepts of all components, systems and sub-systems are being specified. Even if concepts are supposed to be frozen at the end of this phase, modifications to concepts are likely to happen later on in the development process.



Picture 7: 3D view of final total engine assembly (TOA)

CONCEPT VALIDATION

As soon as 3D models from the conceptual design phase are available calculations based on these models can be performed. In this step of validation the following calculations are subject to action:

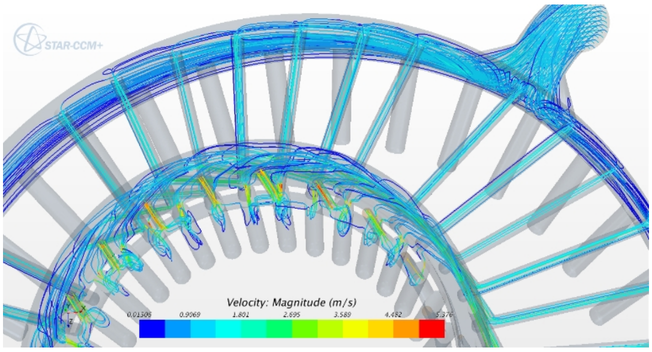
- flow simulations
- natural frequency simulations
- simulation of engine dynamic behaviour
- calculation of specific systems with different own developed tools

Inputs needed:

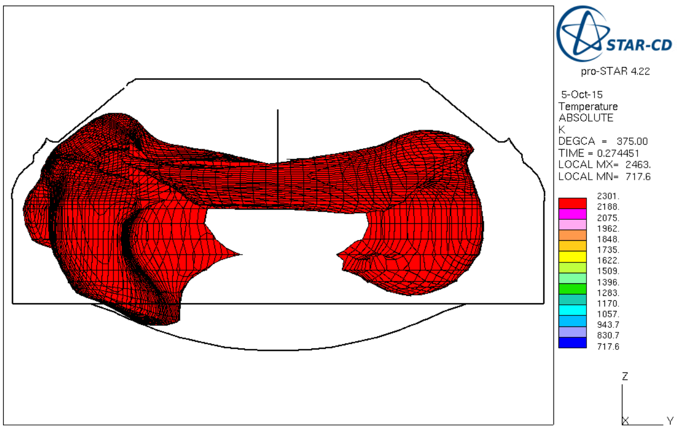
Inputs are 3D models, performance targets, design and technical specification limits.

Activities and Tools needed:

The tools being used for Computational Fluid Dynamics (CFD) are StarCD and Starccm+. Even if StarCD is older it is still used due to its advantages for moving meshes, for instance in combustion rooms. For mesh generation also Ansys is used. Picture 8 shows the flow velocity in the cooling bores of the cylinder cover in order to simulate the flow distribution of the cooling water.

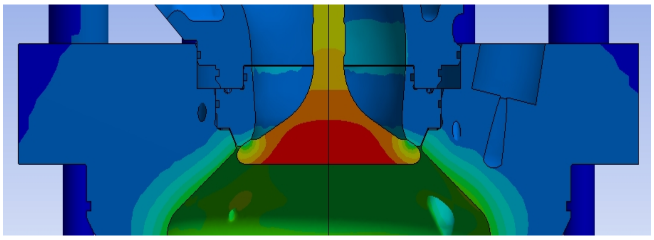


Picture 8: CFD Visualisation of flow speed in cooling bores of cylinder cover



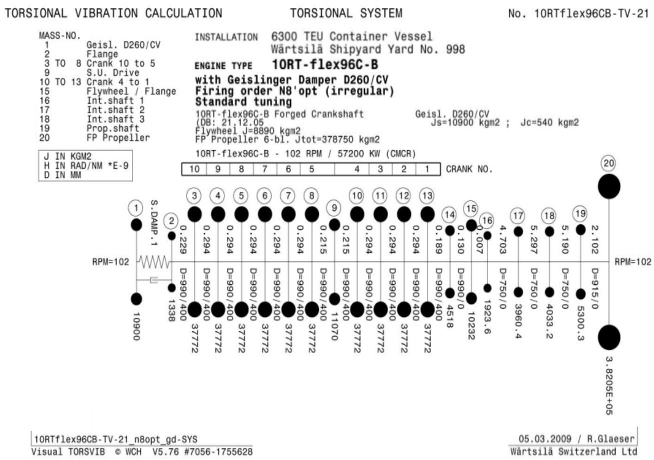
Picture 9: Temperature isocontours during combustion

Picture 9 is a visualization of the heat expansion through the combustion process. This sets the boundaries for the simulation of component temperatures with Ansys as shown in Picture 10.

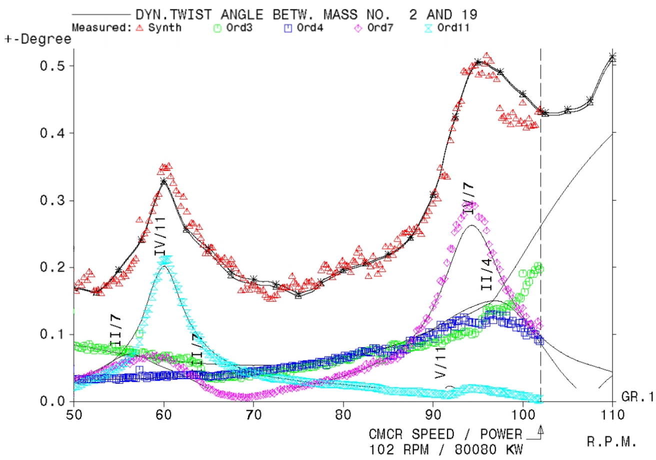


Picture 10: FEM calculation of temperatures of components around the combustion room

For torsional vibration analysis of the crankshaft VisualTorsvib is the program in use. This is an in house development and licensed to several external companies as: Germanischer Lloyd, NK, JMU, IVECO, Metaldyn, OK and Renold. Picture 11 shows the input mask for the torsional system. Depending on the results it will be decided if the torsional vibrations in the system comply with the corresponding rules and if not what kind of countermeasures are needed, e.g. torsional vibration damper, tuning wheel, etc. As an example, Picture 12 shows the comparison between the calculated and measured values.

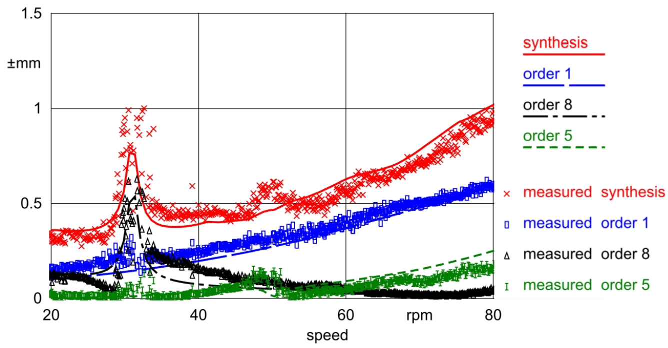


Picture 11: Definition of torsional system in VisualTorsvib



Picture 12: Comparison of calculated values and measured data in VisualTorsvib

Axial vibrations & alignment is calculated in EnDyn, another tool that has been developed in house and nowadays also in use by our customers. Picture 13 shows the comparison of calculated and measured data of axial displacement at free end. This calculation shows if the crankshaft can take the load within set boundaries. The result is subject to acceptance by the classification societies. Other calculations of dynamic components are made with Matlab Simulink.



Picture 13: Axial displacement at free end calculated (lines) in EnDyn and measured values (dots)

Outputs:

The calculation results confirm the correctness of assumptions during conceptual design and form the boundaries for the detailed design phase.

DETAILED DESIGN

In the detailed design phase of two-stroke engine development the engine design needs to be finalized with all details including standard parts to enable the engine builder to physically produce the engine. The design has been validated beforehand by virtual analysis and design reviews. The main part in this phase in terms of effort is the preparation of technical drawings and supporting documentation, such as technical specifications. Only a complete document package including all specified deliverables allows the licensee to properly manufacture parts and build the engine.

Inputs needed:

The validated design models from previous phases including all component specifications form the basis for the detailed design phase. In practice the change from the conceptual or basic design phase to the detailed design phase is rather a transition over a period of time than a single step. In addition, due to the nature of product development there is a tendency to have more than one iterations until a concept can be finally released for detailed design.

Tools needed:

Similar to the conceptual design phase the most important system in this phase is the CAD system. With its functionalities for drawing preparation it enables the transformation of 3D components and assemblies to 2D drawings with all dimensions and tolerances also including the Bill of Material (BoM).

Activities:

The focus is on finalization of 3D models of all design groups. The final design needs to be specified with all details required for engine production. This includes standard parts, such as nuts, bolts, gaskets, etc. An important aspect in the detailed design phase is the analysis of potential collisions between components on the engine. Nowadays modern CAD systems offer various options to perform this kind of analysis.

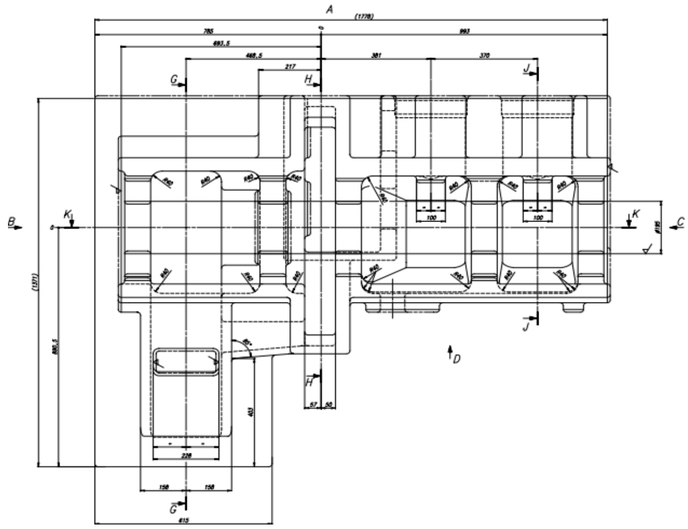
For the part of technical drawing creation the target is to prepare the information required for manufacturing and assembly in a way which supports suppliers and sub-suppliers in the best way. In case of piping systems and steel structures this means separate drawings for welding and machining since these activities may be performed by different companies. In order to fully specify a component for manufacturing the 2D drawing has to include not only dimensions but also geometric tolerances which will safeguard proper fit and function of a part in an assembly. This information is currently only added in the phase of 2D drawing creation. However there are strategies to include this kind of information already into the metadata of a 3D- model. Even today suppliers are able to manufacture individual components based on 3D data delivered from WinGD. In case of complex components the drawing structure from main drawing to detailed drawing follows the manufacturing sequence in reverse order.

Depending on the engine size the total number of drawings will vary. However, on average an entire engine can be specified by 5'200 technical drawings.

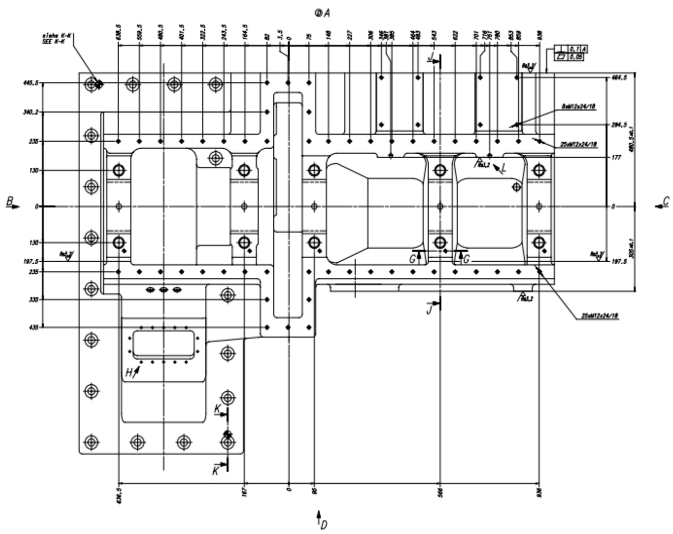
Outputs:

A complete engine drawing package includes but is not limited to:

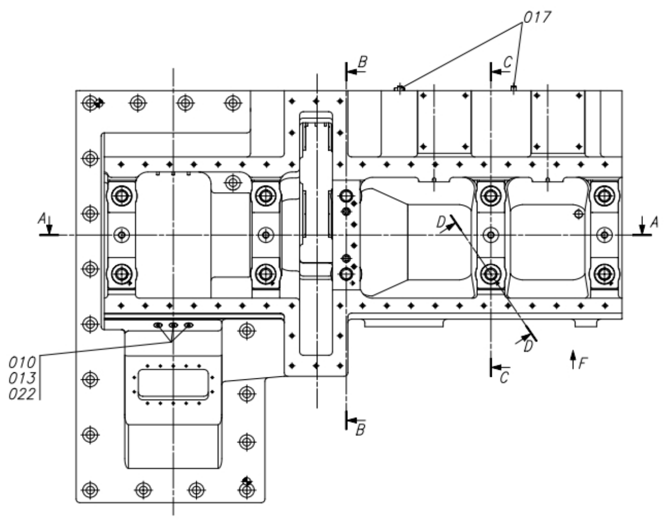
- part drawings
- assembly drawings
- mechanical and electrical diagrams
- specifications (e.g. insulation, painting)
- instructions
- guidelines



Picture 14: Detail of casting drawing supply unit casing



Picture 15: Detail of manufacturing drawing supply unit with geometrical tolerances



Picture 16: Detail of assembly drawing supply unit casing

CONCLUSION

The previous sections gave an insight into the development process of two-stroke engines at WinGD. One of the first steps in the execution phase is the development of the system layout. Part of this step is the definition of all engine systems. The finalized ECD will illustrate all these systems in a schematic and simplified overview. The determination of flow requirements follows the development of the ECD. This activity ask for intense cross-functional coordination since almost all disciplines are involved. The results build the basis for the development of the piping diagrams. Together with the ECD the finalized piping diagrams will allow the complete functional description of the engine. In the conceptual design phase the system layout will get a 3rd dimension by developing a 3D conceptual layout. A TOA of the engine helps to approach further layout definition of components in a structured manner. During concept validation, layout concepts will be analysed by simulation and calculation in order to confirm the actual design approach. In the following detail design phase the engine layout will be completed and the drawing creation will start.

Until now the technical drawing is still the most frequently used instrument to deliver information for engine production to customers. In some cases component production is already based on the 3D data model without the need to have drawings at hand. There is a general trend to shift focus from the 2D drawing to the 3D model for production. However this requires a certain level of automation at production site which is not always given yet depending on where production will take place. Not only for production but also for the engineering there is the need to integrate as much data as possible into suitable data models to guarantee an efficient development and production process. To streamline processes during development and to raise efficiency for delivery of intermediate and final results the target from a process optimization point of view is the integration of tools. Already today the majority of development data can be centralized within a product lifecycle management software. In the case of WinGD this currently applies to design related data, i.e. 3D models, drawings and specifications. The integration of development documentation, such as development and calculation reports can be a further step towards a consistent data model within a PLM solution for product development. On a long term perspective the target should be to establish a homogenous and efficient development approach by having a tools landscape in place which is most beneficial for all parties involved.

NOMENCLATURE

WinGD	Winterthur Gas & Diesel AG
TAT	Type Approval Test
ECD	Engine Control Diagram
P&ID	Piping & Instrumentation Diagram
PLM	Product Lifecycle Management
GTD	General Technical Data
TOA	Total Assembly
CFD	Computational Fluid Dynamics
CAD	Computer Aided Design
BOM	Bill of Material