2002

The Use Of An Integrated CAE/CAD/CAM System During The Compressor Design

M. G. D. de Bortoli
EMBRACO

de Bortoli, M. G. D., " The Use Of An Integrated CAE/CAD/CAM System During The Compressor Design " (2002). *International Compressor Engineering Conference.* Paper 1529.
https://docs.lib.purdue.edu/icec/1529

C9-4

THE USE OF AN INTEGRATED CAE/CAD/CAM SYSTEM DURING THE COMPRESSOR DESIGN

Marcos Giovani Dropa de Bortoli, Research Engineer - EMBRACO, Rua Rui Barbosa 1020
Joinville, SC 89219-901, Brazil; Tel.: +55 (47) 441-2783; Fax: +55 (47) 441-2066
E-Mail: marcos_g_bortoli@embraco.com.br

ABSTRACT

The objective of this work is to present the main advantages of using an integrated CAE/CAD/CAM system in the development of compressors for refrigeration. To illustrate this work, the development of a compressor crankcase is presented. This component is of cast iron, and the main phases of its development are:

- modeling (CAD)
- functional analysis (finite element analysis - FEA)
- manufacture of the cast tool rack
- casting of the crankcase
- machining the crankcase
- experimental tests
- final approval

The entire process is conducted in an integrated CAE/CAD/CAM environment. The three-dimensional model of the crankcase is the basic link among all the diverse phases of development, and permits a great interaction of information to the several disciplines involved in the process. This prevents reworks and eliminates ambiguous information. At the end of the process, a significant increase in the quality of the component and productivity in the development cycle is achieved. An important aspect in the productivity gain is related to the three-dimensional model, which acts without interfaces with the other disciplines of the development process. For example, there is no need for drawings in the initial phase of the process, since the solid model alone has all the information required for the finite element analysis, CNC programs, rapid prototyping, etc. Normally the drawings are only required later, for activities such as: machine planning, dimensional control and documentation.

INTRODUCTION

Since the beginning of the implementation of the CAE/CAD/CAM system at Embraco, in 1987, the emphasis has been on three-dimensional solid modeling. These solid models are the integration vectors among the diverse phases of product development, from conception up to manufacture (Bortoli). To illustrate the advantages of using an integrated CAE/CAD/CAM system during the compressor design, the development of a crankcase compressor is presented. The raw material used for the crankcase is cast iron, and the main development phases are:

- modeling (CAD)
- functional analysis (finite element analysis - FEA)
- manufacture of the cast tool rack
- casting of the crankcase
- machining the crankcase
- experimental tests
- final approval

THE CRANKCASE

The crankcase (illustrated in figure 1) is the central structure of the reciprocating compressor, and supports practically all the internal components of the compressor. It is of cast iron, and some specific regions, where piston, crankshaft, stator and cylinder head are assembled, require machining. In some cases, the springs, suction and discharge chambers are assembled on the crankcase too.

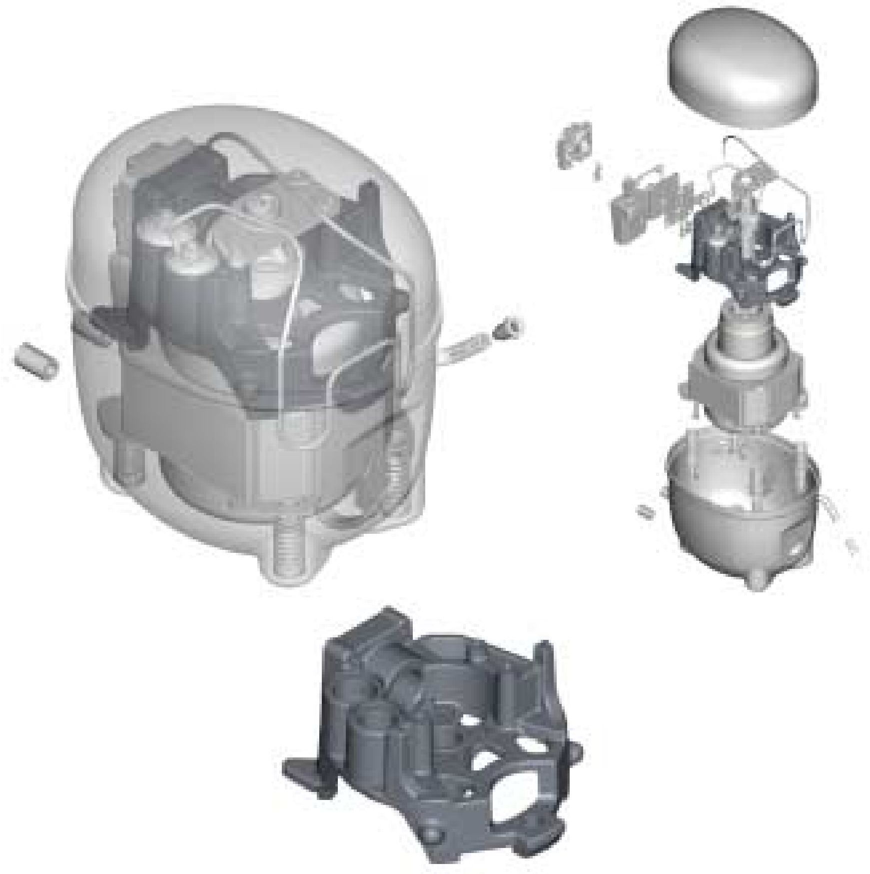


Figure 1: The compressor and crankcase

The main function of the block is to provide sufficient stiffness for the compression mechanism to run adequately. This characteristic is becoming more important because the high efficiency compressors are using low values for piston/cylinder and crankshaft/bearing clearances. Occasional misalignments of the mechanism could reduce the energy efficiency, increase the noise and the wearing, and as a limit condition, can collapse the compressor.

Thus, to fulfill its function, the crankcase must have some geometric characteristics, such as:

- reduced shape errors (roundness and cylinder) in the cylinder and crankshaft bearing region
- perpendicularity between the cylinder and crankshaft bearing
- flatness for the assembly of the stator and cylinder head

The above-mentioned characteristics are the results of the machining process, in honing and grinding operations. The choice of references and the way the crankcase is fixed for the machine process is extremely important for guaranteeing the specified geometric characteristics. In some cases, reinforcements are added to the crankcase simply to guarantee geometric quality requirements in the manufacturing process.

It is important to observe that crankcase quality requirements must not suffer any alteration, even after assembly of the other components, mainly stator and cylinder head. These components use a high torque value for assembly, and could cause undesirable deformities to the crankcase.

Another function of the crankcase is to act as stopper, absorbing any knocks that may occur during compressor transportation. It prevents other more fragile components, such as discharge pipe and suction chamber from being damaged.

The crankcase is one of the heaviest components in the compressor, and this fact deserves special attention. Any single reduction in mass, through an optimization process, can bring a series of benefits, such as:

- cost reduction (less raw material)
- reduction in compressor weight (this could provide a saving in transport costs)
- easier to handle (reduction of ergonomic problems)
- reduction in compressor energy impact

MODELING (CAD)

Today, the CAD systems are in their fourth generation of evolution, characterized by three-dimensional (3D) solid modeling (Sun, Thilmany). These systems use the features technology for the parametric and variational solid modeling, being a fast and intuitive way of generating solid models. From an initial solid, the designer then adds a removing material, through feature type operations, until coming to the final part. Normally, the main features available are: protusion, cut, round, chanfer, sweep, blend, draft and rib (Motta).

The great advantage of these CAD systems is their ability to permit changes to the models (dimensions or shape), in a relatively fast way, without the need to reconstruct the entire model again. This fact is important in the increase of productivity and quality in relation to component development, in that more alternatives can be analyzed, in regard to the available time period for the development of the project.

Other advantages of the 3-D solid modeling are: unambiguous, better visualization, easy creation of cross-sections and auxiliary views, can evaluate weight, CG, inertia, design for assembly, easy assembly creation for checking interferences in three dimensions, and improved interfaces with other disciplines. This interface with others disciplines is vitally important for the integration of all developmental phases of the product within the CAE/CAD/CAM environment (figure 2).

Sometimes, model details are not necessary for the finite element analysis, and can even be inconvenient. If the model has all the details, it will increase the quantity of elements, and naturally, the time required by the CPU to solve the finite element model, as well as the increase to disk space for storing the model. It is not a problem for one model, but during an optimized process, where several dozen models have to be to be analyzed, the difference can be highly expressive. Thus, the models must be simplified for analysis, and following approval according to finite element criteria, all the final details are added to the model, such as fillets, rounds and drafts. Figure 3 presents the difference between two models, one simplified, adjusted for the finite element analysis, and the other concluded one, ready for use in assembly, drawings and manufacturing process.

The creation of the drawing is a fact that must be studied in depth. Unlike in the past, when drawings were required as the input for beginning the manufacturing process, today, only the solid model inside an integrated CAE/CAD/CAM system is needed to start this process. However, the drawing process, which is an arduous task, can be done as a parallel, rather than sequential process. This procedure will reduce the time of cycle development, and the drawing will be ready at the end of process, to check crankcase dimension and to plan the machining process.

FUNCTIONAL ANALYSIS (FINITE ELEMENT ANALYSIS)

Normally, the functional analysis (stiffness) of crankcase is done with the aid of finite element method (FEA). The method is for analyzing crankcase stiffness (the main function) and deformities caused by the manufacturing process as well as that of component assembly.

Until recently, the Achilles' heel for applying the finite element was the generation of the mesh. There were serious problems with the importation of the solid model, normally restricted to the IGES format, with enormous transference and rework problems. Over the last few years, significant improvements have been introduced to the mesh generators, with the models imported in the native language of CAD systems, or even meshes created in proper CAD system. Today, the mesh algorithms are more robust and they allow the creation of meshes on models with complex geometry, such as the compressor crankcase. The mesh is created with few commands, and therefore, can be performed within a few minutes. In the not too distant past, the same work would have taken several hours and, in some cases, may not have been possible at all. To improve the productivity, the hexahedron elements were exchanged for parabolic tetrahedron elements, in which the amount of the latter is equivalent of the quality of the first, eliminating the need for mapped meshes.

The main applications of finite elements in the functional analysis of the crankcase are:

- the stiffness between the cylinder and shaft bearing
- natural frequencies
- crankcase deformity
- mass optimization

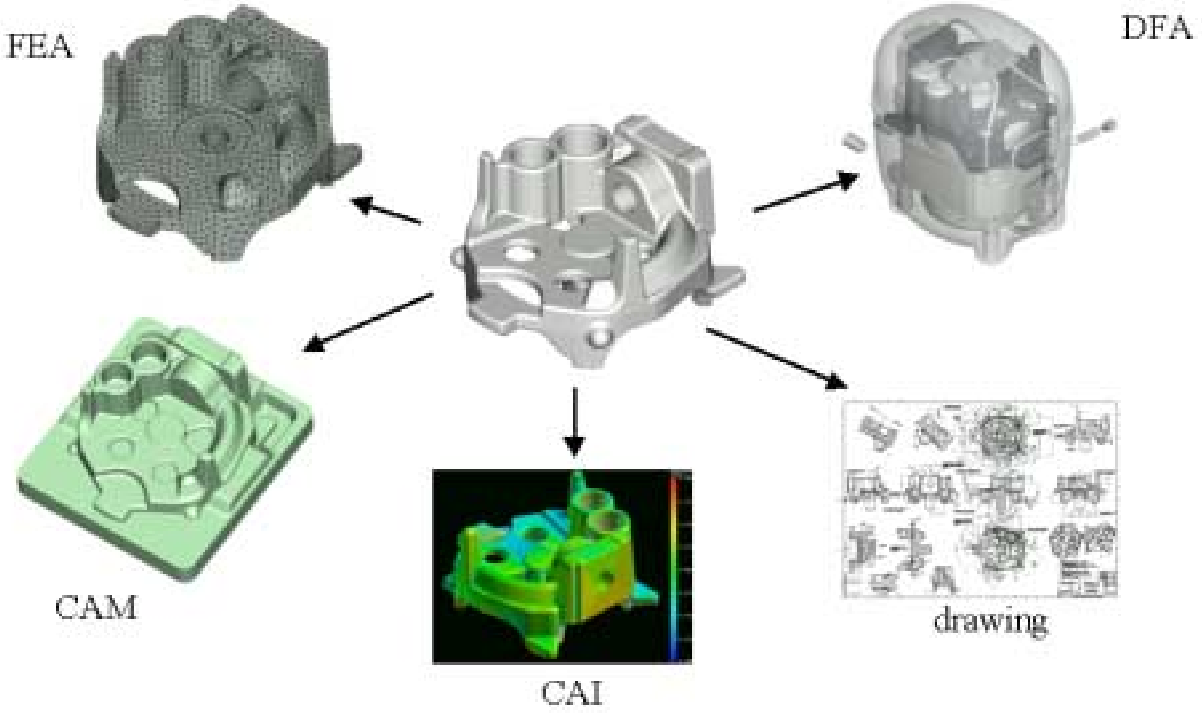


Figure 2: 3D Solid model – the input for multidiscipline tasks

CRANKCASE MANUFACTURING AND APPROVAL

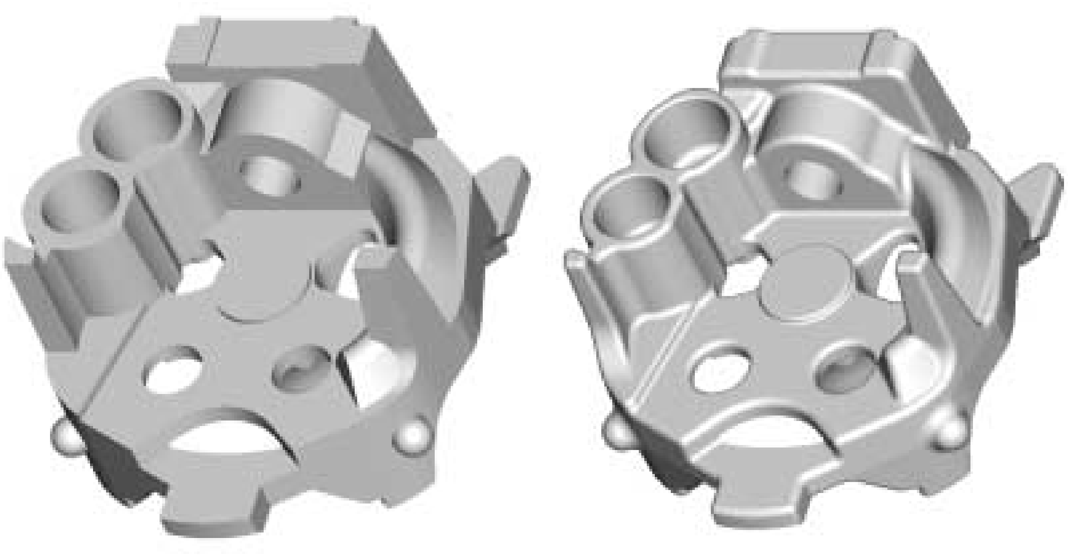
After the model definition (with all the details), and achievement of the project's numerical goals, the next phase is to development the casting tool rack. The first step is to define the division of the mold (see figure 4), and to introduce the thermal expanding effect. There is also the possibility of stimulating the casting process, through specific software, to define the feeders and to improve casting performance.

CNC machines manufacture the casting tool rack, and the programs are written from the solid model of the tool rack. The entire process up to this phase requires only solid models, while drawings can just be considered as desirable. After the machine process, the tool rack is adapted in the casting plates, poured and produced.

After crankcase manufacture, dimensional verification must be performed. It can be done through the traditional process of coordinate measuring machine, or through an optic process, such as digital scanner. It is important to observe that, if the coordinate measuring machine is opted for, then there will have to be a crankcase drawing for the final verification. Otherwise, if optical scanner is used, in which the scanner model is compared to the solid model, the drawing is not required.

The final part of the crankcase manufacturing process is the machining of specific regions, where piston, crankshaft, stator, and cylinder head and, in some cases, the springs are assembled. This process also can be integrated via CAM. In this phase, detailed information concerning the shape and dimensional error tolerances is necessary, and is supplied through drawings.

Crankcase approval occurs in two ways. Firstly, through specific tests, mainly in relation to the stiffness between crankshaft and cylinder. The second part concerns product performance, such as energy efficiency, noise, vibration, start-stop, shake table and transport.



(a) FEA model (b) The final model

Figure 3: The crankcase 3D solid model

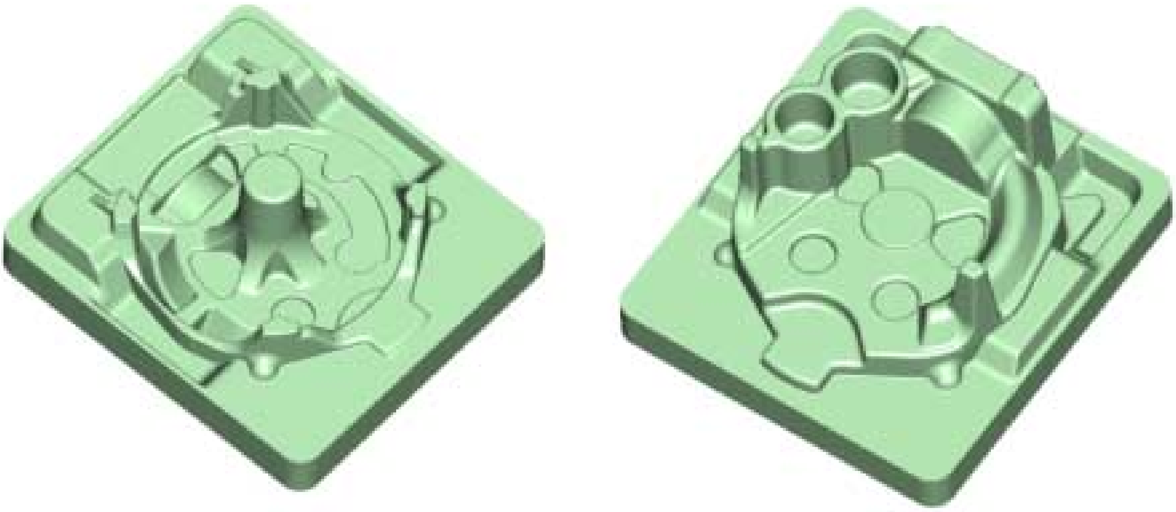
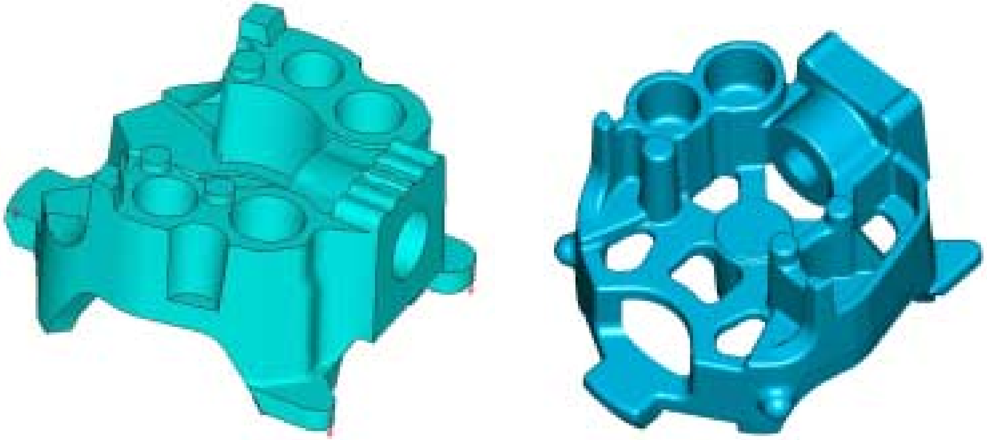


Figure 4: The 3D solid model for the casting tool rack

CONCLUSIONS

The benefits offered by an integrated CAE/CAD/CAM system during the compressor design can be synthesized in two ways: improvement to the quality and reduction in development time. These two factors result in cost reduction. Conceptually these benefits are the same ones presented some time ago. The significant difference between then and now is in the added robustness of the system and its wider solution application, supported by computers of greater processing capacity, which, strangely enough, are not more expensive but in fact are cheaper.

Today, it is much easier to adapt the models than in the past, when almost the entire model had that to be rebuilt for the alteration of a simple radius. With the advent of parametric CAD systems, the productivity for adapting models made process optimization together with finite element techniques feasible. It can be cited that this facility provided a 20% reduction to compressor crankcase mass, as shown in figure 5.



(a) Initial configuration (b) End configuration

Figure 5: Mass process optimization for the crankcase

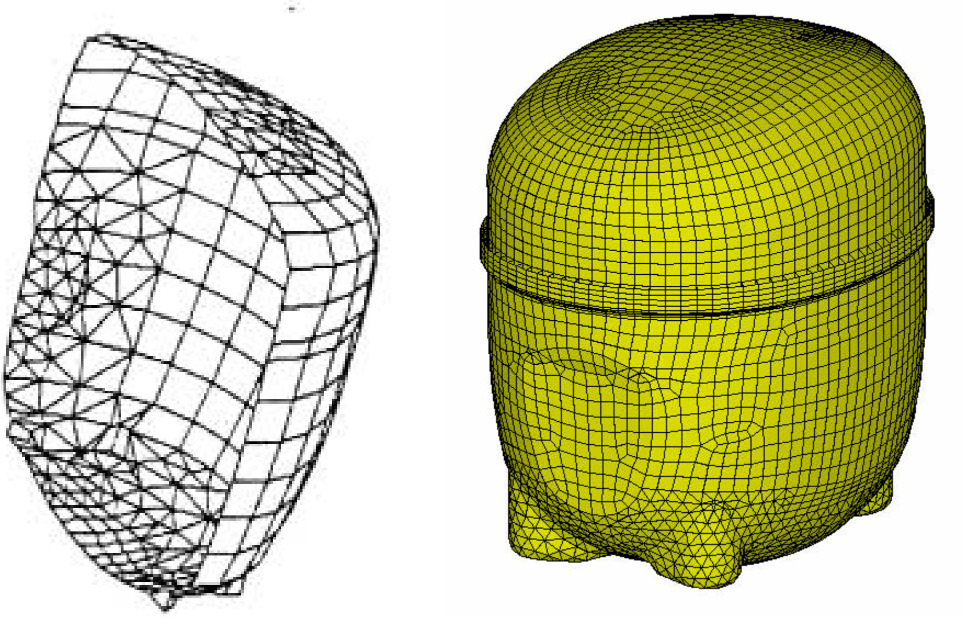
Important improvements have occurred in the importing of models for the generation of finite element mesh. Today the programs allow models to also be imported in the native language of CAD system, in addition to improvements in neutral systems such as IGES. In figure 6, an example of the evolution in the finite element mesh generation process is shown. The model in figure 6-a was created in 1992, and the time taken for creating the mesh was approximately 4 hours. In the figure 6-b, a recent model with many more details and a much more refined mesh, the complete process to create the finite element model only took about 15 minutes, from importation of surface up to the final filing of finite element analysis.

Concerning CAM, there were also advances in productivity and quality. Today, the time required for creating CNC programming for the crankcase tool rack (figure 7) is about three times less than that required to make a shape like the compressor shell (figure 6) in the past. And, without doubt, the difficulties encountered at that time for creating the CNC programming for crankcase tooling would be enormous.

In the specific case of the casting, time gains have also been significant. In a traditional process, i.e. manual construction of the tool rack, the final time for attaining the products would be about 5 times greater. In the current stated periods, manufacturing time is almost the same as that for producing a rapid prototype system, but with significant differences, such as: the component is real, and there are available, not just one, but eventually some hundreds of samples.

The accomplishment of the drawings in a parallel and not sequential process allows a reduction of around 30% in cycle time, after the definition of the 3D model. This allows a significant increase in productivity.

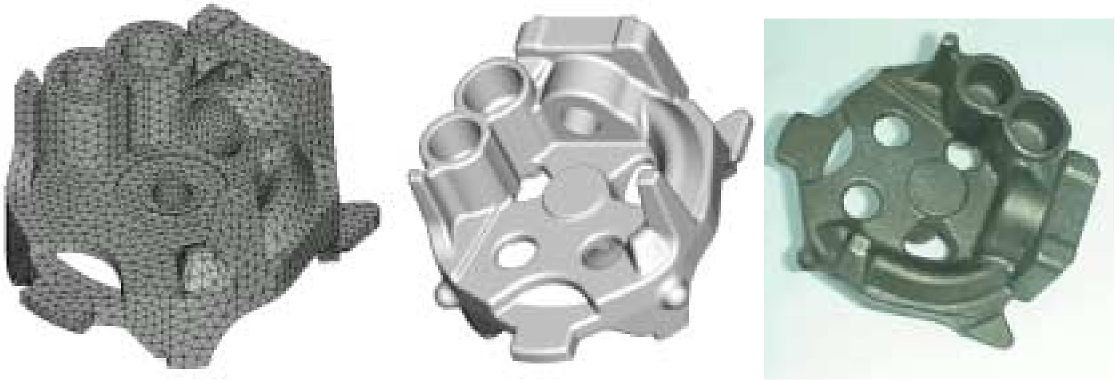
Thus, the use of an integrated CAE/CAD/CAM system helps a lot in the development of new compressors, and allows the designing and manufacturing of compressor components, such as the crankcase (figure 8), to be obtained in a short space of time and with quality.



(a) In 1992 (b) In 2002

Figure 6: The finite element mesh evolution

Figure 7. The real cast tool rack



(a) FEA model (b) CAD model (c) Real component

Figure 8. The crankcase

REFERENCES

Bortoli, Marcos Giovani Dropa., "Concurrent and simultaneous engineering applied to design hermetic refrigeration Compressor", 1992 International Compressor Engineering Conference at Purdue, pp. 687-695, 1992.

Motta, Gastão Dias, "3D Modeling with Solid Edge", Lectra Engenharia e Inf. CAD/CAE/CAM (in Portuguese) [Cited 7 May 2002]. Available from. http://www.cae.com.br/materia_4.htm.

Sun, W., "Introduction to 3D CAD and Solid Modeling", MEM Department., Drexel University [Cited 7 May 2002]. Portable Document Format. Available from http://www.pages.drexel.edu/~sunwei/CADMBTEL-Intro-CADmodel.pdf.

Thilmany, Jean, "Three out of two", Mechanical Engineering, pp. 60-63, September 2001.