Optimization of a brush cutter using knowledge-based engineering

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Emak

Emak manufactures machines for gardening, small-scale agriculture, and civil construction. It develops its two-stroke engines for handheld applications such as chainsaws, brush cutters, and blowers. The aim of the project was to automate as much as possible the generation of a CAD model to be used as a reference for designers during the whole industrialization phase. By implementing and harnessing an advanced process integration workflow, it was possible to reduce design time and obtain a broad view of all potential critical aspects of the machine.

Brush cutter architecture

A brush cutter essentially consists of a motor (in this case an endothermic, single-cylinder two-stroke engine), a transmission system, and a cutting device. A large part of the design work concerns the endothermic unit, which was developed directly in-house, while the transmission system and the cutting device allow less leeway at the design level. As a result, the CAD for the drive unit is far more detailed and complex than the CAD for the transmission system; the cutting device was modelled.

Technical situation at Emak at the start of the project

The company began producing brush cutters in 1972, but only introduced the position of calculation specialist – previously left to more experienced designers – into the technical management team in 2012. It was then that the company began developing spreadsheets to try to prevent individual problems in the various functional groups while taking advantage of past experience.

Over the years, the spreadsheets have been refined and enriched with new features, including the ability to perform Monte Carlo analyses based on the tolerances used in established manufacturing processes.

At the start of the project, the following spreadsheets were being used:

- CAE1402D02: screw tightening analysis
- CAE1402D03: crank gear cages and bearings analysis
- CAE1402D04: starting unit analysis
- CAE1402D06: flywheel-cylinder system analysis
- CAE1402D09: clutch-transmission system analysis
- CAE1402D10: cylinder layout analysis
- CAE1402D11: cutting force analysis

The disadvantage of these spreadsheets is that they do not interact with each other and therefore, every time a new machine is introduced, the same data must be copied across the various sheets, wasting unnecessary time, and possibly leading to typographical errors on the part of the calculation specialist.

Reorganization of the spreadsheets

It was therefore necessary to modify the spreadsheets so that they interacted with each other; spreadsheet CAE1402D01 functions as a collector, distributing the variables necessary for the calculations, and distributing the ensuing results to the other spreadsheets tasked with checking specific issues.

In addition, the flow of data generation was analysed in depth, starting with the limited data representing market demand.

The underlying idea is that all these variables can be used to construct a parametric CAD model capable of providing the designer with a starting point for any new machine to be designed.

Keeping the CAD model up to date across an increasing number of configurations required considerable effort. It was also necessary to introduce some spreadsheet constraints that did not exist before. This initial phase of work lasted approximately six months. Only three pieces of data are necessary to start the calculation (see Fig. 1):

- the maximum power
- the maximum power speed
- the maximum torque speed

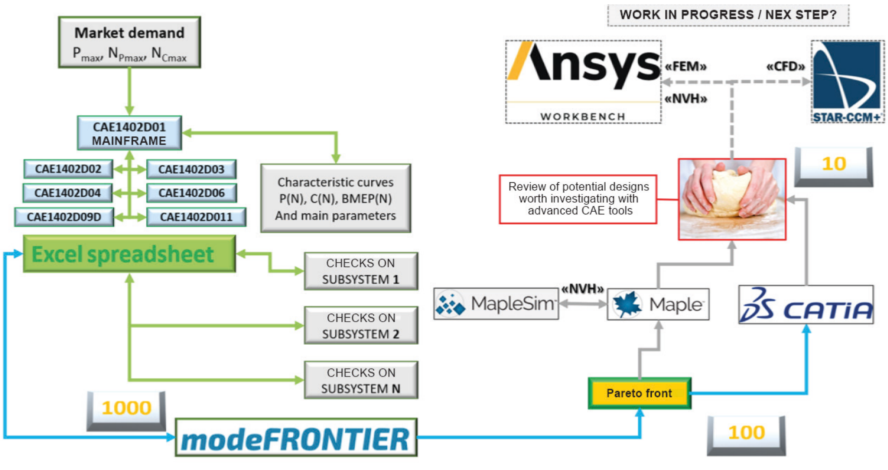

Fig. 1. The workflow created to generate and analyse the best brush cutter designs.

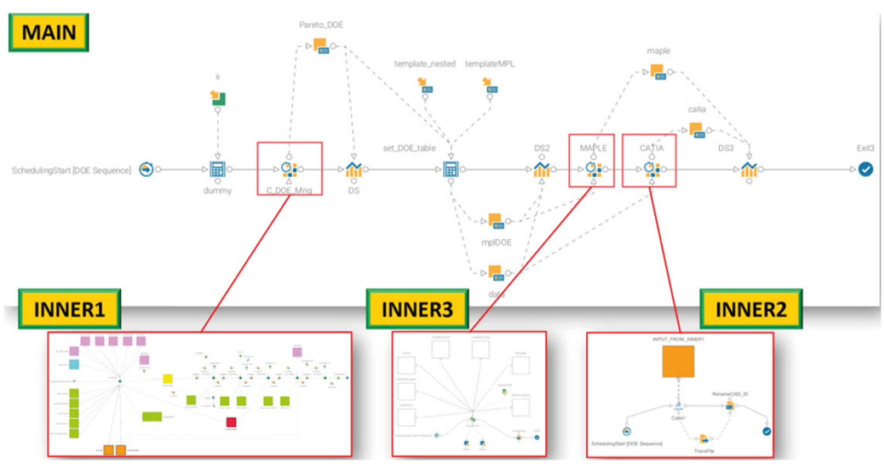

Fig. 2. The nested workflow used in modeFRONTIER.

modeFRONTIER methodology

In order to manage the large number of activities required to characterize a particular brush cutter design, it was decided to organize the workflow according to nested processes. We therefore created a MAIN process which launches the following activity-specific processes in sequence (Fig.2):

- INNER1: performs the actual optimization using the previously mentioned spreadsheets; we use the pilOPT algorithm here because it has proven to be effective and is able to produce a sufficiently populated Pareto front that can be used for further considerations.
- INNER2: automatically creates a CAD drawing from each Pareto front design. The CAD drawings are then numbered sequentially to allow them to be simultaneously opened by the user (see Fig.5).
- INNER3: prepares and launches the multi-body model needed to calculate the excitants; a folder containing all the necessary information is created for each Pareto front design (see Fig.6).

As can be seen in Fig. 1, while the pilOPT process is capable of analysing around 1,000 designs overnight, the Pareto front that is generally extracted is an order of magnitude less (around 100 designs). A subsequent "manual" review of the data reduces the number of feasible designs by a further order of magnitude (around 10 designs). The design engineer can then choose the most suitable design for the case according to other selection criteria that have not been codified within the workflow.

The post-processing phase of the Pareto front takes a morning to complete. As a result, the CAD upon which to develop and industrialize the new brush cutter can be generated within a single working day, from the moment the calculation is begun.

Optimization strategy

The following objectives were set for optimizing the brush cutter:

- min {total mass M_tot}
- min {alternate mass M_alt}
- min {height ING_H}
- min [cross sectional dimension ING_tra}
- min {axial dimension ING_ass}

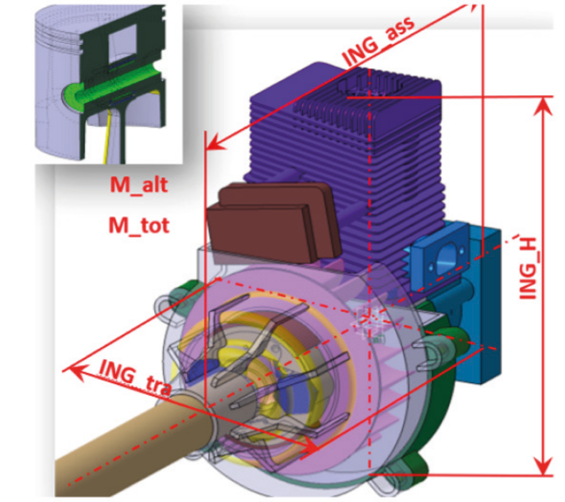

Fig. 3. The objectives defined for the INNER1 process

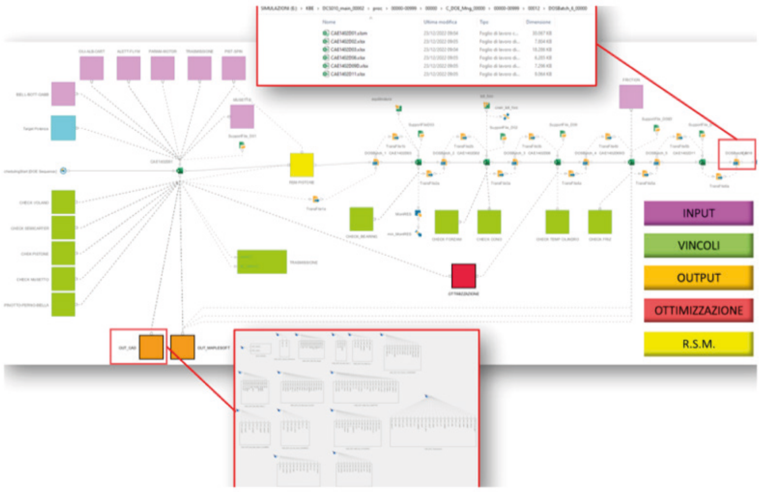

Fig. 4. The INNER1 workflow that optimizes the brush cutter.

Obviously, this refers to the representative values of the machine and not to the real ones (Fig. 3); in fact, many components such as intake filter, carburetor, muffler, ignition system, handles, etc. are not included in the calculation of total mass, nor are they managed at CAD level. At the end of the process of the INNER1 workflow (see Fig. 4), the full set of spreadsheets containing all the specific variables of the analysed design, whether feasible or unfeasible, is saved.

Feasible or unfeasible? Monte Carlo analysis

According to modeFRONTIER, a design is feasible when it satisfies all the imposed constraints. These constraints are nothing more than verifications of component safety coefficients, compliance with certain type-approval standards, geometric verifications to ensure functionality and CAD updates of components. All these constraints are estimated for nominal conditions of the design, without any knowledge of the potential consequences of compliance with the constraints if the production process is at the specification limit.

For this purpose, Monte Carlo analysis is used. It basically consists of introducing the usual manufacturing process tolerances for the input variables, associating a statistical model for data variations (not necessarily a Gaussian distribution), and establishing a reference population (that intercepts a 0.1% defect). The calculation of the results is, therefore, subject to a certain variability resulting from the tolerances imposed as input.

To ensure that a constraint is respected in practice as well as in theory, it is necessary to require at least 95% of the resulting population to respect the constraint. All this translates into a doubling of the number of constraints required for a design to be considered feasible. In total, 70 constraints are imposed in the system.

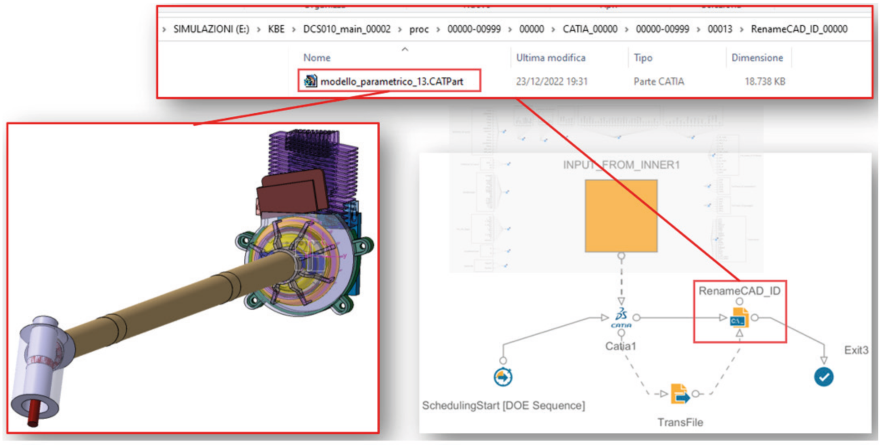

Fig. 5. The INNER2 workflow to automatically generate the CAD drawings.

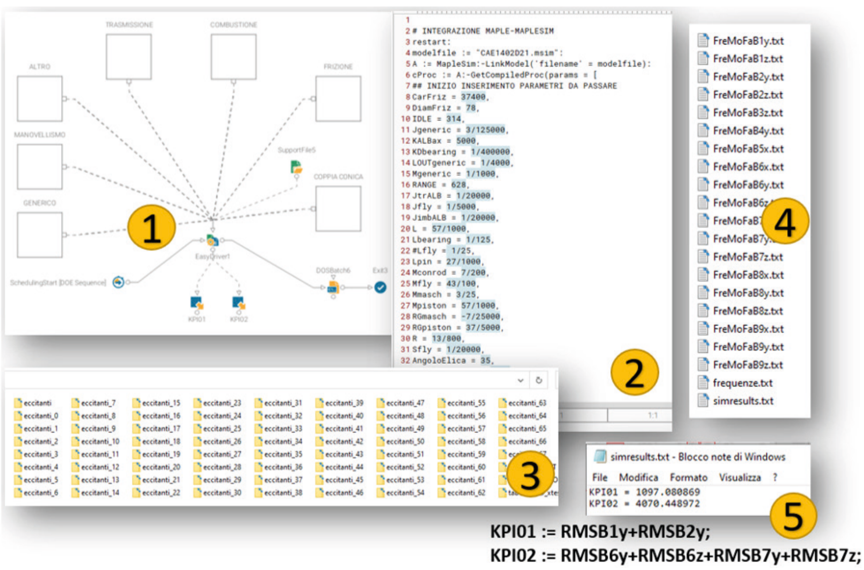

Fig. 6. The INNER3 process qualifies the Pareto designs from a vibrational point of view.

The use of RSM (response surface modelling)

modeFRONTIER initially interpreted the attempt to reduce the alternate mass of the single-cylinder endothermic engine as a reduction of the die-casting thickness to the lower limit of the assigned variation range. To remedy this, it was necessary to include a check on the piston deformation, which can be calculated by means of a thermo-structural finite element simulation. It was therefore necessary to create a parametric CAD model of only the piston-pin-rod system, run it through Ansys Workbench, and perform the calculation by extracting the necessary information. At this point, we asked modeFRONTIER to create a response surface on approximately 300 designs of the piston deformation, enabling us to greatly reduce the calculation time for the INNER1 process.

An initial look at vibration

Single-cylinder endothermic engines are susceptible to vibration due to the impossibility of balancing alternating and rotating forces. However, partial balancing of the crankshaft is possible, and is factored into the complex calculation system.

However, it is not possible to balance all the static imbalances that accumulate randomly on the inside of the rotor, in particular the flywheel, clutch and tool. Without going into detail, we can state that the lower the exciters acting on the machine structure, the lower the resulting vibrations will be. Therefore, the INNER3 process extracts all the forces that the rotor side exerts on the structure and uses them to summarize certain qualitative indices of the vibration level: in particular, the transverse vibrations in mean effective value (RMS) measured on the bench bearings and tool-side bearings (KPI01 and KPI02) are evaluated (see Fig. 6).

modeFRONTIER manages the multi-body parametric model realized in MAPLESIM with a MAPLE script to which the input variables are passed; the resulting time histories, calculated over a normalized one-second cycle, are then post-processed via MAPLE and transformed into frequencies for potential use with FEM codes (fatigue analysis).

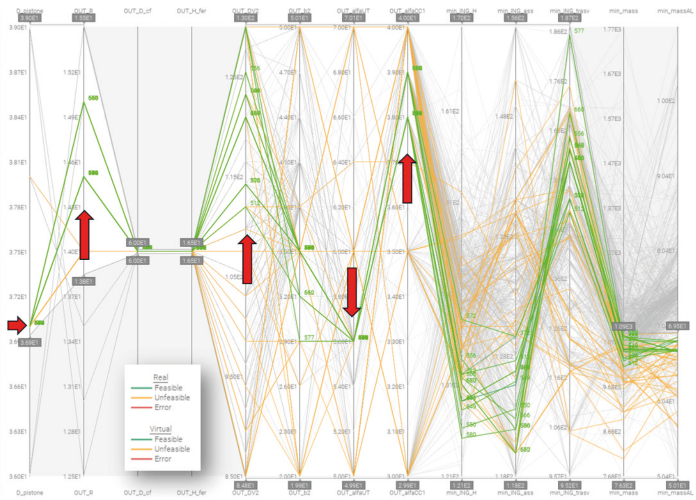

Fig. 7. Analysis of results using a parallel chart.

Results

The most efficient way to analyse the solutions generated is to highlight the Pareto front in a parallel chart, concentrating on the input and output variables of greatest interest (Fig. 7). This allows the main trends in the input variables that allow for Pareto optimal designs to be identified. Furthermore, by filtering down the values of total mass and alternate mass, one can further filter out those few designs (<10) that constitute the “best of the best”.

Compared to the designs currently in production, the objectives are being achieved with a different engine bore and, in general, a different stroke-to-size ratio than the existing architectures. This aspect would never have emerged had we not also included an assessment of the machine's potential vibratory aspects in a preliminary analysis. This was made possible by using the created workflow, which provides a 360° view of all critical aspects of the machine before even producing any CAD model.

Compared to the reference case, the process estimates an approximate 7% mass reduction, which we consider to be overstated compared to what can actually be achieved, specifically because it does not consider all the surrounding components and only evaluates the components over which we have the most control.

About Emak

For the past 25 years, Emak has been one of the leading names associated with the care and maintenance of parks, gardens, and green spaces. Our brands — Efco, Oleo-Mac, Bertolini and Nibbi — are known and valued by professional and hobby users the world over. With four brands and as many production facilities to its name, plus seven branches and 22 product families, our company is constantly expanding. The quality and excellence in design of our products have won us many international awards, and we are regarded as setting the benchmark for internal combustion engine technology and its applications in our chosen sector. We are a leading global player, offering innovative solutions for gardening, agriculture, forestry, and industry. We manufacture and distribute machines, components, and accessories of high technological value, designed to render the activity of our customers easier and more efficient. We have a flexible manufacturing model focused on the high added-value aspects of engineering, industrialization, and assembly. Our production systems are geared to “lean manufacturing” and involve supply chains as part of an extended factory model.

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