Machine Design Optimization Based on Finite Element Analysis in a High Throughput Computing Environment

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Project Objectives

To develop software that efficiently optimizes the design of various types of machines using finite element (FE) analysis in a high throughput computing environment to achieve the best possible performance results in the least amount of computational time.

Machine Design Optimization Technique

The differential evolution (DE) strategy is one of the genetic algorithm procedures that it is good for finding the global maximum value in nonlinear system. It has the reputation of simple to implement, easy to use, reliable, and fast. So DE is applied in this research to explore the multi dimensional variable design space in order to find the most promising design to meet the required performance.

For the machine design optimization problem, the first thing is to decide parameters that can be varied and parameters that need to be fixed. The second thing is to define the range for each variable parameter, and the actual value for each fixed parameter. After that, all the parameters are transferred to part of the modified DE code, in order to create the finite element script (VB script). Then the finite element script is executed in JMag, a commercial software used for FE analysis, to estimate performance of each design. The FE analysis results are written in a text file and used by the main DE code to evaluate the objective function. If the design is the optimum, the optimization run will end, otherwise, the whole process will be repeated again until the optimum is found. The flow chart describing the machine optimization routine is shown in Fig. 1.

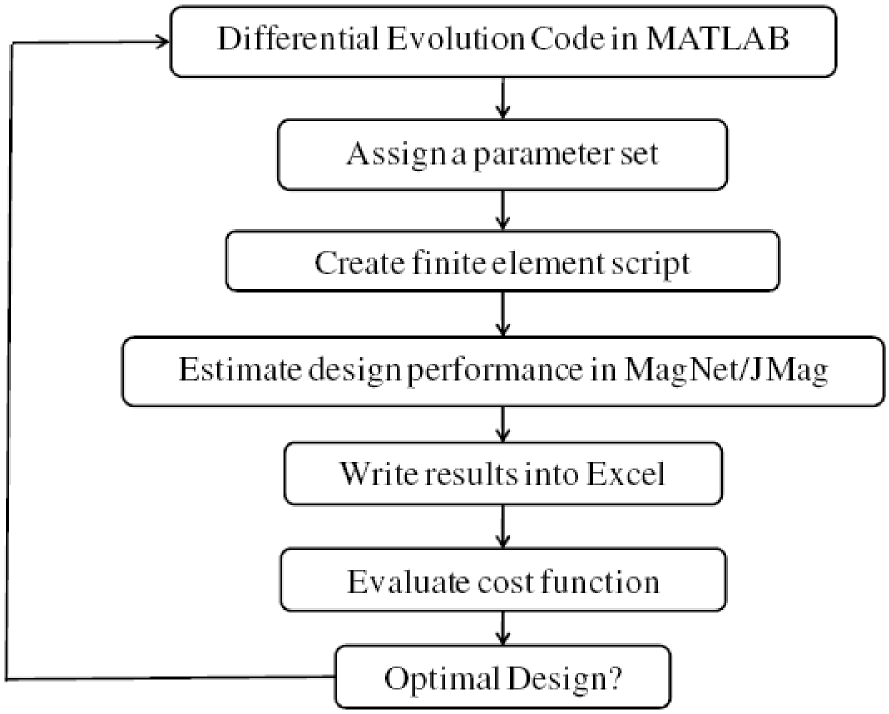

Fig. 1: Machine Optimization Routine

FE Based Optimization

The FE analysis is a numerical technique for finding approximate solutions of partial differential equations as well as integral equations. Its final result is from adding calculation results on every finite element. So FE analysis is more accurate than magnetic circuit analysis. Because of its high accuracy, FE analysis was chosen to evaluate the performance for each machine design in this research. However, the price paid for high accuracy is large computing time. For a single design, the execution time difference between FE analysis and magnetic circuit analysis could be more than 50 : 1. As a result, in order to find the optimum design in a reasonable period of time, this FE based optimization has to be realized in a high throughput computing environment.

Optimization in Condor – High Throughput Computing Environment

Fortunately, Condor, a high throughput computing environment, which harnesses the parallel processing capability of more than a thousand workstation computers, is available in UW-Madison. Moreover, JSOL Corp. has generously donated 100 JMag licenses, making it possible to analyze up to 100 candidate machines at the same time. The flow chart for future Condor based optimization is shown in Fig. 2. It has similar routine shown in Fig.1. The difference is that instead of evaluating designs in each generation one by one on a single computer, all the performances of all the design can be calculated simultaneously in Condor.

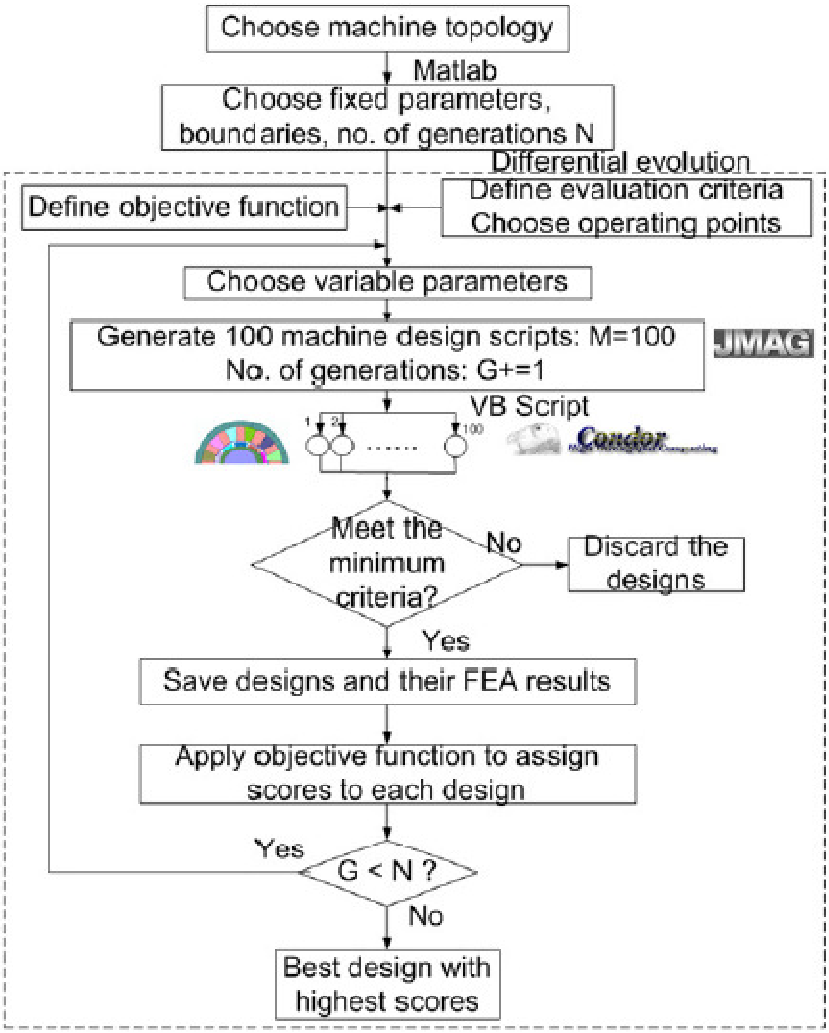

Fig. 2: Future Optimization in CONDOR

Solution: Process and Required Resource

Step 1: Run the main DE code (written in Matlab) on a single computer, which acts as a “master” machine to control the whole optimization process.

Operating system: Either Windows or Linux, having Matlab installed.

Output: 100 finite element script (VB script) files for each generation. Each VB script is around 10 kB

Input: 100 text files showing the results from FE analysis. Each text file is around 10 kB

Estimated time: 30 min for each generation, around 20 generations to converge. Total time = 30 min*20 = 10 hr.

Step 2: Transform VB scripts into ".jcf" files on "slave" machines, processors in Condor pool. One hundred "slave" machines run at the same time

Operating system: Windows, having JMag installed.

Output: ".jcf" file. Each ".jcf" file is around 10 kB

Input: VB script. Each VB scrip is around 10 kB

Step 3: Evaluate the ".jcf"model file and get FE analysis result on each "slave" machine.

Operating system: Windows, having JMag installed.

Output: ".plot" file. The maximum size for each ".plot" file is around 500 MB

Input: ". Jcf" file. Each ".jcf" file is around 10 kB

Step 4: Extract result from ".plot" file on each "slave" machine.

Operating system: Windows, having JMag installed.

Output: text file, containing result information, should be fed back to the master machine to launch another generation (Start **Step 1** again). Each text file is around 10 kB.

Input: ".plot" file. The maximum size for each ".plot" file is around 500 MB.

Status and Future Plans

Members from UW-Madison Condor team, engineer from JSOL, and our research team are working together to write and install optimization program in Condor computers. The surface and interior PM machines are selected as initial targets for optimization. Later on, this optimization technique will be extended to other types of machines. In longer term, the program will be expanded to include structural and thermal analysis, in order to realize a system level optimization.

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