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Research Design and Identification of the Project Methodology Solutions Using the Finite Element Method

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Abstract. The anticipation of the process variables (temperature, cutting forces, and stress distribution) plays an important role in the tool geometry design and cutting conditions optimization. The researchers found that the anticipation of these variables experimentally is costly both from a time requirement and financial point of view. Having this information, the finite element model becomes the most favourable alternative and most useful in all aspects. Existing Empirical models are very useful in demonstrating these matters, but if tests have not been carried out to create these models types, then it brings benefits in the improvement specifically to the process itself. This paper is focus to conduct the research and discover a methodical design solution based on the finite element method. This entails defining the input data used within the research framework, including: application type, finite element analysis, material model, and, of course, choosing the process parameters. After determining the input data, following the completion of the theoretical models of the experiment, respecting the finite element model, the output will take into account the final results of the selected research. In order to obtain optimal solutions and to increase the precision and accuracy of the obtained results, it is necessary to validate this using the experiment.

1. Introduction
For this research, a wide bibliographic material, which includes over 200 national and international references, was studied. Throughout this paper, reference will be made to the most important among them. Since the 2000s, the FEA experimental method has been advanced [1]. Regarding to the modelling and experimental technique chosen to be used, the researchers is very important to understand, not only their capability, but also the existing theory. Due to the cutting process complexity, more and more frequently, numerical approaches have been developed and adopted to replace direct experimental approaches; which are costly and time-consuming. Among the numerical techniques, the most frequently encountered during the past two decades is the Finite Element Method [2]. Using the Finite Element applications, the cutting process has focused particularly on: setting of the material properties related to the deformation, strain rate and temperature [3]; modelling tool - chip interface depending to the friction [4]; the functions and variables of the analysis, such as the cutting...
forces, the chip geometry, stresses, deformation, temperature distribution in the workpiece, etc. [5]. Therefore, in order to achieve a research focused on the experiment with the finite element, certain conditions must be fulfilled and reached, such as: selection of the FEA application; selection of the simulation method; introducing the material properties and the cutting tool properties in the FEA application; selection of the material model; selection of the cutting process, the cutting regime and the geometric parameters of the tool which will constitute the influence factors of the cutting process; selection of geometric, state and actions parameters that are analysed in the experiment.

2. Research design using the finite element methods

2.1. Modelling type selection

Currently, there is a wide range of finite element applications. These applications are based on two modelling types: the implicit modelling [6] and the explicit modelling [7]. The finite element applications which assume an implicit modelling offers a variety of factors such as: bars, plates, membranes, axial symmetrical, 3D general solid. When choosing certain items types, the imposing automatic mathematical models on which they are based should be taken into account. The explicit modelling involves the selection of the mathematical model of the physical problem. In this situation, there are two possibilities: either searching for a finite element analysis program which can be used to solve the mathematical model, or creating such a program. Therefore, the explicit modelling involves much more experience in programming and resources than the implicit modelling. Generally a combination between implicit and explicit modelling is used. Physical problem to be modelled is divided into sub problems. Therefore, the conventional sub problems for which exist corresponding resolution programs may be resolved by implicit modelling, while those requiring special processing can be resolved only by explicit modelling.

2.2. Selection of the FEA application

Among the applications that can be used to the simulation achievement, DEFORM is one of the most used. In the Figure 1 it is indicated as a percentage grade used by FEA applications during the past two decades.

![Figure 1. A percentage grade used by FEA applications during the past two decades (1998 – 2018).](image)

2.3. Selection of the modelling technique

In the finite element method application the calculation of the main structures, there are mainly two methods of describing the material motions associated with the mesh network of the structure, which are the Euler and Lagrange models [8]. The strong point of each method are actually the weak point of the other, and for this reason the two approaches actually complement each other. Arbitrary Lagrange - Euler (ALE) has been developed primarily to benefit from the advantages of the two traditional
techniques and to avoid their disadvantages, using each technique when it may be advantageous to do so. From another perspective of both described methods, both Lagrange and Euler are based on the definition of a meshing network [9]. To re-mesh the bodies which recorded large deformation, it is recommended to use the SPH technique (Smooth Particle Hydrodynamics) in which, unlike the previous models, there no longer appear issues related to severe distortion of the elements which would lead to numeric instability, [9].

In Figure 2, an analysis of the methods justifying the FEA experiments during the past two decades has been shown. As is clear from the graph shown in Figure 2, Lagrange was the most used technique, due to the fact that the procedure has advantages in terms of meeting the desired objectives pursued in carrying out experiments with the cutting processes simulation.

![Figure 2. Percent comparison of FEA experiments during the past two decades.](image)

### 2.4. Material type selection

Once the conditions determining the application of the finite element analysis and the experimental methods necessary to conduct the research, another step consists in choosing the material type. The selection and use of a particular material model is one of the most important components of the simulation process using the finite element method, since the material selection fundamentally influences the analysis results. In the cutting process, the more the chosen material model approaches the behaviour of the workpiece, the more accurate the results are [12]. The evolution of the use of different types of material models from 1998 to the present is highlighted in Figure 3.

![Figure 3. Comparison of the use of the various types of material models.](image)

### 2.5. Selection of the workpiece material

The next necessary condition to perform the finite element simulation of the cutting process and experiment is constituted by the selection of the workpiece material [13]. Figure 4 shows the percentage comparison of the frequency of the work-piece materials used, from which it can be seen that steels were most often used, accounting for more than 60% of the total.

![Figure 4. Comparison of the frequency of work-piece materials.](image)
2.6. Selection of the cutting operation and process parameters
Another necessary step to be accomplished in carrying out the researches pursued in this paper is the selection of the cutting operation. According to the bibliographic study it was found that turning is the most frequent operation approached in the cutting processes study. In figure 5 is highlighted the percentage comparison on the frequency of the cutting operations used, clearly the superiority of the turning process, consisting of 50% of the total studies identified between 1998 and 2018 [14, 15].

2.7. Selection of the influence factors
Another aspect to be defined is to determine the tool geometry parameters died in the simulation. Figure 6 shows that the most commonly used element was the clearance angle of the tool, which was identified in 54% of all the bibliographic material studies. At the same time, it is necessary to establish the cutting regime parameters. It was found that the most used parameter in this respect is the cutting speed, which accounts for almost half of the total (Figure 7) [15, 16].
2.8. Response selection
Once the influence factors have been established, it is necessary to set the research response. Figure 8 shows the most common responses. It was found that the most studied geometric factor is the chip formation, which appears as a study object in over 60% of the research papers identified in the bibliographic material [17, 18, 19, 20]. The influence of the cutting regime parameters is also felt on the state and action factors. As Figure 9 shows, following the frequency comparison of these parameters, it can be seen that the most studied factors were tensions, forces, and temperature [21].

3. Designing the experimental research
In order to achieve the experimental research design, it is necessary to go through some stages consisting of: theoretical model achievement; experimental method identification; the workpiece material selection; the tool type and cutting regime selection; measuring devices selection; design of fixing devices; performing the experiment (preparation of the workpiece, tools, devices and CNC machine; conduct an experiment simulation; necessary adjustments; start the experiment in a predefined order of the types and number of measurements; completing the experiment and making the final measurements; recording the obtained values); data collection and information centralization.
4. Conclusions
This paper presents the needed steps to design a research and identify methodical design solutions using the finite element method. This approach has been chosen, given that the variables anticipation of the experimental cutting process is costly both in terms of time as well as financially. Therefore, the finite element simulation becomes the most favourable and most convenient alternative in all aspects. In order to achieve the proposed objective, it was necessary to establish the input data used in the research, which includes: the application type used, the finite element analysis method, the material model, and, of course, the process parameters selection. After determining the input data following the theoretical models of the experiment, respectively the finite element simulation, the output data will take into account the determination of the studied research direction. In order to obtain the optimal solutions and at the same time to increase the accuracy of the obtained results, at the simulations completion, it is necessary to perform the results validation with the experiment.

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