Integration of CAE Modeling and Artificial Intelligence Systems to Support Manufacturing of Plastic Microparts

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Abstract— Micrometer-scale parts requirements demand an improvement of the development of the micro-manufacturing industry. This fact is due to current technological advances which require small parts with more complex geometrical characteristics, microparts with more precise dimensional characteristics, microparts with better quality aspect and microparts with improved quality operating characteristics. Therefore, the manufacturing processes to obtain high quality microinjection parts is increasingly complicated, requiring much more time (a greater number of cycles) and knowledge from the expert operator, which makes the process unprofitable, as well as highly dependent of the operator and increasing the final costs of microinjection parts for the user. This paper presents the development of an artificial intelligence system based on the integration of CAE modeling, with fuzzy logic techniques and neural networks techniques to support the operator of the injection machine on the selection of optimal machine process parameters to produce good quality microparts in fewer process cycles. Tests performed with this intelligent integration system development have demonstrated 30% improvement in the efficiency of injection processes.

Keywords: Micro-parts, Plastic Parts, Artificial Intelligence, Neural Networks, Injection Processes, CAE Systems

I. INTRODUCTION

The development and technological progress generated in today's society has impacted several disciplines such as health, telecommunications, transport, commerce, education and industrial production. Today, there are many activities that can be done only with the movement of the hand thanks to the great variety of machines and devices that perform tasks which required great physical effort from the person, consuming large amounts of time and energy.

Although there is no doubt that current technology has facilitated people's lives in many ways, the manufacturing processes of different devices are still very complex. Knowing that people every day want these devices to be smaller for easy handling and acquisition, it is even harder to produce them, especially when they are small and with smaller components. Technological development is taking the need of production of millimeter and micrometric parts will be seen in an increasingly significant way in sectors such as automotive, medicine, electronics and biotechnology among others [1].

Taking into account the need for production of plastic parts, different manufacturing techniques based on material molding, extraction and injection have arisen, but many of these are based on the experience of the operator, who must be an expert in the control of process parameters that affect geometric and material variables [2]. In addition, if such methods are to be applied in the manufacture of millimeter and/or micrometric scale parts, precision in variable manipulation must be high, which in turn increases production times, as well as materials and operating costs.

The use of artificial intelligence systems is increasingly implemented in different areas, although there are still many sectors that depend on the experience and knowledge of technicians and operators. One area affected by the lack of implementation of these systems is microinjection: although this process requires enormous amounts of precision in parameter control, it relies heavily on operator control, who in turn are prone to make mistakes and human failures [3]. Fuzzy logic systems allow managing qualitative functions in parts, based on process rules compliance [4], which are already established by operators and operating manuals; and as there are many applications for controllers. Fuzzy machines would serve as a support system for operators and process control [5], thus reducing defects in the injection molding process [6].

Neural networks are more complex systems based on interactions and training [7], which can synthesize large numbers of parameters from different learning techniques and predict the real behavior of the system, achieving values close to system operation. Applying this technique in micro-injection
processes makes it possible to carry out a complete analysis of the parameters that affect the system, thus establishing the appropriate behavior to obtain a part without defects. These systems, aside from serving as support to process optimization [8], give real and indicated values for the desired part, granting more control tools to the operator, and therefore decreasing the load and the dependence that is generated.

This article seeks to show how artificial intelligence systems were implemented in the development of a support software for micro-injection processes, generalizing diverse generic parts with millimeter and micrometric characteristics, from the study of these. Everything is done making use of design tools and CAE simulation, which gave an approach to the standardization of forms and processes, allowing to make predictions to the real behavior of the system by means of fuzzy logic and neural networks, with which it was possible to obtain the most appropriate variables that affect the manufacturing parameters reducing process cycles, decreasing production times, saving materials and optimizing the system.

II. CONTENT DEVELOPMENT

Several stages of analysis and experimentation were developed, establishing the most important input variables to be taken into account by the system as well as defining the most relevant injection parameter processes to use them as output variables of system and their relationships with quality control of parts that require injection processes.

Design stages and manufacturing process stages are described follow:

A. Design and geometric analysis of micro plastic parts

Considering the need to build a generic intelligent system, that could be used in the manufacturing of any microinjection part, varied geometrical part designs were selected to be used during the creation of this system.

CAD models for more than 30 parts of a micrometric scale and with diverse shape characteristics were made, defining geometric variations that could be studied to obtain indices of a standardized behavior (Figure 1.). Seven variations were made on the geometry of each part to study their behavior depending on the stress tests that were performed: finally, the parts with better behavior were standardized and considered for the injection research process.

B. Analysis of injection process by CAE simulation

After CAD designs were selected, CAE analyses were carried out. Variations considered included injection parameters, injection point, material, filling time, material temperature, mold temperature, injection pressure and cooling time. Injection flow behavior resulted of each parameter change made on the simulation of each part designed, was analyzed taking record of the deformation indexes that appeared on each of the parts.

For each part, about 6 variations were made for each of the parameters, identifying which variation affected the final behavior of the material (Figure 2). Finally, log tables were created for each part where all the variations of the injection parameters were saved.

C. Database Creation

Records taken from the geometric variations and injection parameter changes were included in a database, which included 3600 elements of data taken from 20 control variables and 180-part variations. (Figure 3.).

An Artificial Vision System tool was designed using Image Processing MATLAB®, Toolbox to obtain all graphic analyses from the results generated after capture and interpretation of the graphs obtained during the CAE simulation (Figure 4.). The created database stores all the records that have been generated from the developed study, in order to find a behavior that suits the desired indexes.
Matlab code, to load STL files:

```matlab
[FileName Path]=uigetfile({*.stl'},'Abrir Documento');
set(handles.edit1,'string',num2str(Path));
set(handles.edit2,'string',num2str(FileName));
model = createpde(3);
importGeometry(model,[Path FileName]);
figure(1)
pdegplot(model,'FaceLabels','on')
saveas(figure(1),'pieza','tif')
myImage = imread('pieza.tif');
axes(handles.axes1);
imshow(myImage);
```

Matlab code, image processing:

```matlab
fullFileName = string(Path)+string(Image);
[gifImage, cmap] = imread(fullFileName, 'Frames', 'all');
[rows, columns, numColorChannels, numImages] = size(gifImage);
grImage = zeros(rows, columns, 3, numImages, 'uint8');
hFig = figure;
for k = 1 : numImages
    thisFrame = gifImage(:,:,k);
    thisRGB = uint8(255 * ind2rgb(thisFrame, cmap));
    imshow(thisRGB);
    rgbImage(:,:,k) = thisRGB;
    caption = sprintf('Frame %#d of %d', k, numImages);
    title(caption);
    drawnow;
end
close(hFig);
```

Matlab code, data loading:

```matlab
Path = get(handles.edit3,'String');
Pathtxt = erase(Path,"Images\");
filetext = fileread([Pathtxt 'Predeterminado_word.html']);
idnm = strfind(filetext,'Nombre de material = ');
for c=1
    n=1;
    while c<=2
        n=n+1;
        if(filetext(idnm+n)=='<')
            c=3;
        else
            Nombre_de_material(n)=filetext(idnm+(n-1));
        end
    end
    Nombre_de_material(n)=filetext(idnm+(n-1));
deleteMe = isspace(Nombre_de_material);
    Nombre_de_material(deleteMe) = [];
end
```

C. Design of predictive systems based on neural networks

Database developed from CAE analyses was established as a first resource to create the integrated system. Afterwards, three geometric analysis processes were designed: the first one was established as a STL (Standard Triangle Language) file reading system where, by means of matrix analysis, the parts are studied in the three geometric planes (X, Y, Z), determining the most significant vertices and the geometry that identifies them. As a second option, the user can make use CAE-like software to determine the geometry of the part. For this, it is necessary to load the data based on the geometrical and injection studies and provided by the software which allows the system to recognize and determine part dimension. Third option is carried out by Image Processing MATLAB®, Toolbox where the dimensions of the part are determined through photographs taken of a previous model of the desired part. For this option, it was necessary to create a system, where the part was studied by rotating it on a fixed axis and taking photographs of different angles to determine its geometry (Figure 5.).
set(handles.pushbutton3,'visible','off')
set(handles.pushbutton4,'visible','off')
[FileName Path]=uigetfile({'*.stl'},'Cargar Modelo .STL');
set(handles.edit4,'string',num2str(Path));
set(handles.edit5,'string',num2str(FileName));
set(handles.pushbutton3,'visible','on')
set(handles.pushbutton4,'visible','on')
axes(handles.axes1);
fv = stlread([Path FileName]);
patch(fv,'FaceColor', [0.8 0.8 1.0], ...
    'EdgeColor', 'none', ...
    'FaceLighting', 'gouraud', ...
    'AmbientStrength', 0.15);
camlight('headlight');
material('dull');
axis('image');
view([-135 35]);

- Matlab code, study STL dimensions
  Path=get(handles.edit4,'String');
  FileName=get(handles.edit5,'String');
  [F,V,N] = stlread([Path FileName]);
  vm=max(V);
  set(handles.edit1,'string',num2str(vm(1)));
  set(handles.edit2,'string',num2str(vm(2)));
  set(handles.edit3,'string',num2str(vm(3)));
  set(handles.pushbutton5,'visible','on')

**D. Neural Network Design**

Once the geometric analysis of a desired part is concluded, data interaction is carried out to obtain injection recommendations. Regression machine learning for neural network was identified as the most suited process to be applied to this system. (Figure 6).

Considering the behavior of the system, the variables stored in the database were established as input, whereas the output was determined as the geometric dimensions of the desired part with a deformation index tending to zero. Neural networks MATLAB® Toolbox was used in order to first establish the number of internal layers and a maximum of learning cycles: 10 internal layers and a maximum of 1000 interactions were selected, to obtain the results without being affected by over-learning (Figure 8.).

**E. Report recommendations**

The trained neural network could determine which injection parameters are best suited for the process. In order to report back to the user of the recommended injection parameters, the program makes a report where it considers all the variables detected and the changes that the operator must make on the process in order to obtain the least amount of deformations and defects on the part in each injection cycle. An error indicator
analyzes the real and ideal behavior generated and finally, the injection operator will be informed of the veracity of the system and if it is necessary to perform more than one injection cycle.

**F. Put into practice**

To determine the efficiency of the system, tests were carried out with generic parts with special characteristics thus: parts with radial concentric characteristics, parts with flat face characteristics and parts with solid characteristics with which the real behavior of the system could be determined. (Figure 8.)

To produce injection parts, it was necessary to build a modular prototype mold to be employed in Micro-Injection Molding Experiments where each part is manufactured replacing the investigated cavity in a short period according to their particular characteristics [9]. Mold was made of aluminum due to its thermal capacity and behavior during an effort situation. Real injection tests were carried out with a system developed to assist the expert operator.

**IV. RESULTS**

There was evidence of a clear improvement in the injection processes as well as in process efficiency comparing the tests with the system developed assisting the operator on foot of machine, with the same test done without the assistance of the system developed.

Over 100 tests with operator and process conditions were performed, applying experimental design techniques such as the Taguchi method, [10], in order to give a scientific structure and a complete evaluation of the performance of the optimized system, carrying out comparative analyses of the parameters offered by the system and the operator. Finally, it was found that the use of the system yielded more appropriate values for the injection process depending on the characteristics of each part, generating a reduction of about 30% in the number of injection cycles required to obtain a good quality injection part (Figure 9).
IV. CONCLUSIONS

1. The integration of CAE systems, fuzzy logic systems and neural network algorithms allow to optimally predict the behavior of a material in the injection molding process, reducing the quantity of injection cycles required to obtain a part with micrometric and/or millimeter characteristics by up to 30%.

2. Tests developed showed efficiency of Intelligent Systems applied to injection molding process: it is better when applied directly to the process, as it is possible to include external variables and real behavior of polymeric material, through a quality inspection by the operator of the injected parts.

3. CAE system integrated in the developed intelligent system, allows for the consideration of every geometric parameter and material behavior as important input variables, giving to this system the adaptability required to be used to any kind of geometry and any kind of polymeric injection material.

4. Artificial Neural Network integrated to this system give learning ability, thus generating more optimal parameters in each new interaction and approaching an ideal behavior, without generating regressions in the processes.

5. An integrated Fuzzy Logic System allows incorporation of quality inspection defects as food of machine, giving to system the adaptability to take into account the possible impacts from each external variable and inherent material changes in the production of injected part, each injection cycle.

6. Efficiency system will be improved using more varied generic parts and a greater variety of polymeric materials and extending tests to different geometric characteristics of injection parts.

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