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# FUZZY LOGIC BASED ALGORITHM IN CHOOSING OF THE WORK PIECES IN EARLY DESIGN STAGE

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***Abstract:*** *Manufacturing and product design experts consider the product early design stage as the most important stage of the design process, because it influences all stages of the product life cycle. A lot of recent papers were dedicated to the development of approaches regarding the decision-making in the early design stage. The present paper deals with the problem of the work piece choosing for arbor type pieces. The proposed algorithm is based on fuzzy logic. The main idea is to formalize the knowledge regarding production volume, arbor shape and dimensions, piece complexity, loading, etc. using fuzzy sets and then to take the work piece choosing decision through inference rules.*

***Key words:*** *design, manufacturing, product life cycle, decision-making, fuzzy sets, fuzzy logic.*

## 1. INTRODUCTION

Manufacturing and product design experts consider the product early design stage as the most important stage of the design process, because it influences all stages of the product life cycle. A bad decision in the early design stage will have serious consequences. This is the reason why a lot of recent papers were dedicated to the development of approaches regarding the decision-making in the early design stage [1]. The present paper presents the problem of the work piece choosing for arbor type pieces. The proposed algorithm is based on fuzzy logic. The main idea is to formalize the knowledge regarding production volume, arbor shape and dimensions, piece complexity, materials, etc, using fuzzy sets and then to take the work piece choosing decision through inference rules that are specified to fuzzy logic method.

One of the main advantages of fuzzy logic is the possibility to formalize knowledge related to manipulated variables and their handling in a manner that is similar to a human expert, based on the inference rules.

As an example, Fig. 1 shows the fuzzy set "high temperature". Thus, 27°C temperature is considered High Temperature", with a *membership degree* $\mu = 0.75$. The temperature above 30ºC is 100% high. Using the concept of fuzzy set, we can refine our statements about the manipulated variables [3, 4].

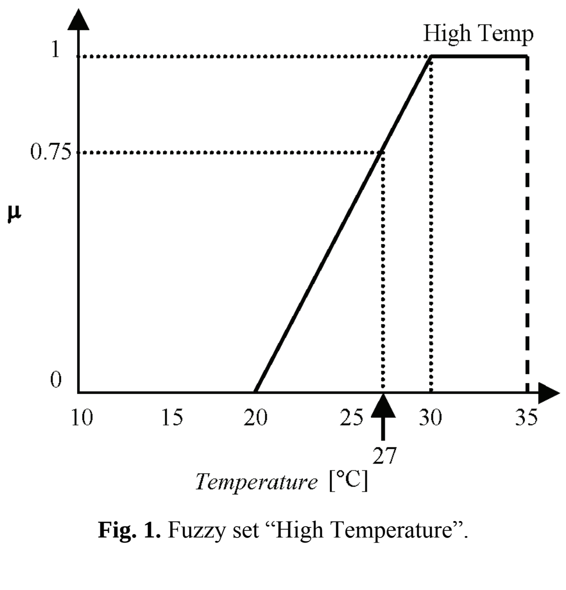


**Fig. 1.** Fuzzy set "High Temperature".

## 2. THE CHOOSING OF WORK PIECES

As it is well known, one of the capital questions for any manufacturing or design engineer is "simple or elaborated work piece?". The choosing of a simple and cheap work piece involves later high processing costs. The opposite situation – the choosing of a complex but more expensive work piece – generates lower later processing costs. The optimization problem consists of the choosing of the right work piece for the current conditions [2, 5]:

- piece's complexity;
- piece's material, shape and dimensions;
- operating conditions (load, fatigue);
- production volume;
- available capital and equipment, etc.

The proposed methodology is focused on the choosing of work pieces for arbors. For this kind of pieces a lot of work pieces can be used:

- laminated bars;
- forged work pieces;
- open-die forged work pieces;
- close-die / drop forged work pieces;
- casted work pieces.

The choosing of the right work piece is a complicated decision making problem. In many cases this problem is solved empirically, based on the experience of the manufacturer. Complicated economical calculus is required to determine the right work piece.

In order to simplify the presentation, this study presents an algorithm for the choosing of work pieces in the case of arbors manufacturing.

For the purposes of this paper, it was taken into account laminated bars, forged and drop forged work pieces as possible work pieces for a given arbor.

## 3. THE ALGORITHM FOR DECISION-MAKING

### 3.1. The fuzzy logic algorithm description

The algorithm is based on formalizing of quantitative and qualitative factors on the work pieces choosing, and then on the performing of a judgment using inference rules. The last stage consists of the interpretation of the results. This three stages are a common characteristic of fuzzy logic applications, which needs to specife the following elements:

- the fuzzyfication of the input variables;
- the inference rules;
- the defuzzyfication of the output variable.

The manipulated variable of the proposed algorithm are the following:

- the production volume;
- the ratio of the maximum and minimum diameters of the manufactured part;
- the part's mass;
- the intensity of the loading conditions.

For each of them a so called linguistic variable must be defined. Fig. 2 shows the linguistic variable "Production Volume", PV, which consists of three fuzzy sets:

- *Low*: It describes the low/singulaire production volume;
- *Medium*: It describes a medium production volume;
- *High*: It describes the high/mass production volume.

The set *Low* is trapezoidal, with the big base of 100 and the small base of 10, in semi-logarithmic coordinates. The set *High* is also trapezoidal, but using the big base from 100 to 10 000 and the small base from 1 000 to 10 000. The set *Medium* is triangular, with the base from 10 to 1 000.

The linguistic variable "Parts Mass", PM, is very similar to the linguistic variable "Production Volume". It is described by Fig. 3.

The linguistic variable "Diameters Ratio", which is presented in Fig. 4, consists of three fuzzy sets:

- *Small*: It describes the small diameters ratio. It is a triangular set, with the base of 0.5;
- *Medium*: It describes a medium diameters ratio and consists of a triangle with the base of 1;

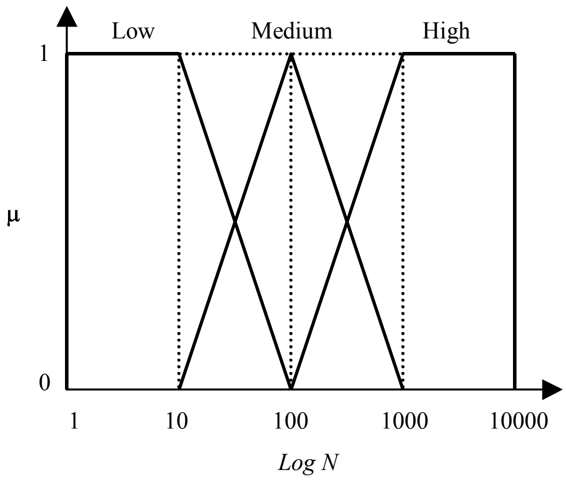


**Fig. 2.** Linguistic variable "Production Volume".

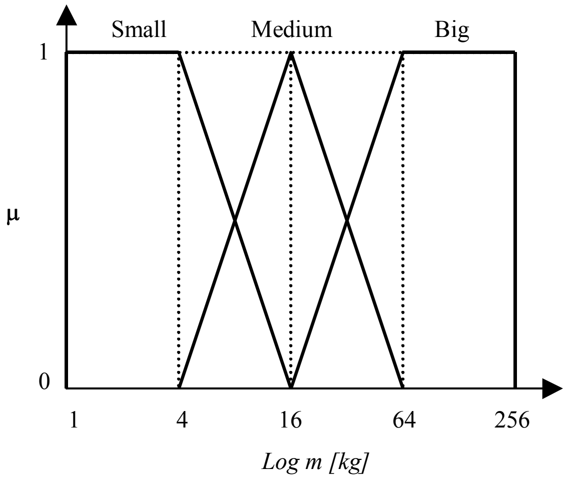


**Fig. 3.** Linguistic variable "Parts Mass".

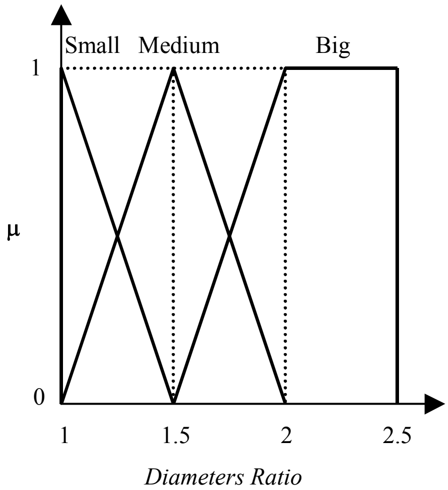


**Fig. 4.** Linguistic variable "Diameters Ratio".

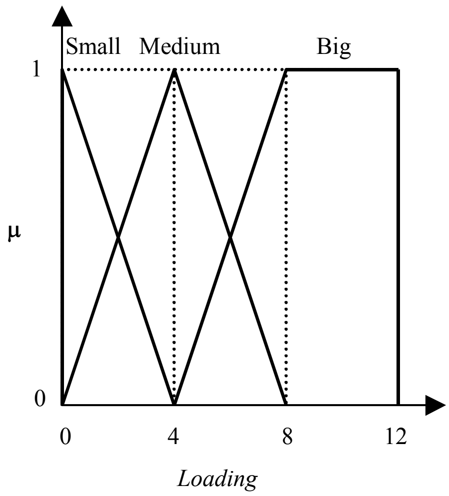


**Fig. 5.** Linguistic variable "Loading".

- *High*: It describes a big diameters ratio. It is a trapezoidal set, with the big base of 1 and the small base of 0.5.

The linguistic variable "Loading", L, is very similar to the linguistic variable "Diameters Ratio". It is described by Fig. 5. The scale is user defined, depending on the specific loading conditions.

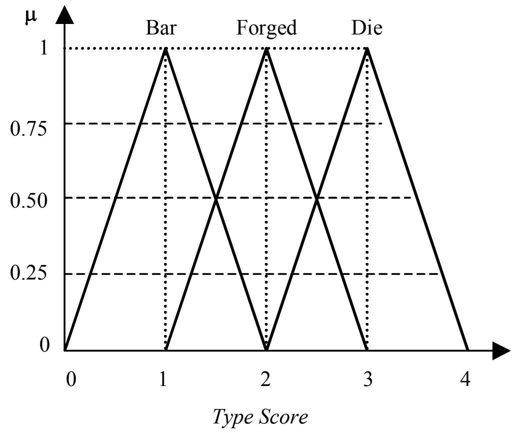


**Fig. 6.** Linguistic variable “Work Piece Type”.

The output variable is the type of work piece. A user-defined scale formalizes it. It is represented by the linguistic variable “Work Piece Type”, WPT, which has the following characteristics (Fig. 6):

- three fuzzy sets as follows: Bar, Forged and Die;
- all the sets are triangular, with the base of 2 points.

The inference rules establish the connection between the input variables and the output variable. For example an inference rule could be the following:

IF *VP* IS High AND *DR* IS Big AND *PM* IS Medium AND *L* IS High THEN *WPT* IS Die.

For this application the inference rules use the same form, with the *minimum* algebraic operator of the AND operator [3, 4]. Table 1 shows the synthesis of the inference rules.

The cumulative score that is obtained through the inferences makes the interpretation of the results. It is a proper defuzzyfication method, because it takes into account the frequency of the implications, not only the amplitude of the membership degrees that are associated to Bar, Forged and Die fuzzy sets.

### 3.2. Example

The following example shows how the algorithm is applied to a given application, which is characterized by the data:

- production volume: 180 parts/year;
- $D_{max}/D_{min}$: 1.75;
- mass: 32 kg;
- loading intensity: 7.

The fuzzification establishes the member degrees of the input variables to the correspomding fuzzy sets:

- production volume (Fig. 7):

$$\mu_{Medium}(180) = 0.75$$
$$\mu_{High}(180) = 0.25$$

- $D_{max}/D_{min}$ (Fig. 8):

$$\mu_{Medium}(1.75) = 0.50$$
$$\mu_{Big}(1.75) = 0.50$$

- mass (Fig. 9):

$$\mu_{Medium}(32) = 0.50$$
$$\mu_{Big}(32) = 0.50$$

*Table 1*

**Lookup table of inference rules**

| | | | **Production volume** | | |
|---|---|---|---|---|---|
| **Dia-Ratio** | **Mass** | **Load** | **Low** | **Medium** | **High** |
| **Small** | **Small** | **Small** | Bar | Bar | Bar |
| | | **Med.** | Bar | Bar | Bar |
| | | **Big** | Bar | Bar | Bar |
| | **Med.** | **Small** | Bar | Bar | Bar |
| | | **Med.** | Bar | Bar | Bar |
| | | **Big** | Bar | Bar | Bar |
| | **Big** | **Small** | Bar | Bar | Bar |
| | | **Med.** | Bar | Bar | Bar |
| | | **Big** | Forged | Bar | Bar |
| **Med.** | **Small** | **Small** | Bar | Die | Die |
| | | **Med.** | Bar | Die | Die |
| | | **Big** | Forged | Die | Die |
| | **Med.** | **Small** | Bar | Die | Die |
| | | **Med.** | Forged | Die | Die |
| | | **Big** | Forged | ***Die*** | ***Die*** |
| | **Big** | **Small** | Forged | Forged | Die |
| | | **Med.** | Forged | Forged | Die |
| | | **Big** | Forged | ***Forged*** | ***Die*** |
| **Big** | **Small** | **Small** | Bar | Die | Die |
| | | **Med.** | Forged | Die | Die |
| | | **Big** | Forged | Die | Die |
| | **Med.** | **Small** | Forged | Die | Die |
| | | **Med.** | Forged | ***Die*** | ***Die*** |
| | | **Big** | Forged | ***Die*** | ***Die*** |
| | **Big** | **Small** | Forged | Die | Die |
| | | **Med.** | Forged | ***Die*** | ***Die*** |
| | | **Big** | Forged | ***Die*** | ***Die*** |

- loading intensity (Fig. 10):

$$\mu_{Medium}(7) = 0.25$$
$$\mu_{Big}(7) = 0.75 .$$

The inference rules that are involved are emphasized in the table 1 by bold and italic characters. The membership degrees for each inference are computed as in the following example:

IF *VP* IS Medium AND *DR* IS Medium AND *PM* IS Medium AND *L* IS Medium THEN *WPT* IS Die

$$\mu_{Die} = \min(0.75; 0.50; 0.50; 0.25) = 0.25 .$$

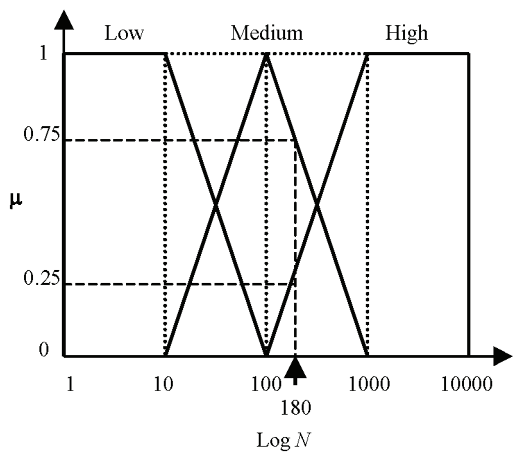


**Fig. 7.** Fuzzyfication of “Production Volume”.

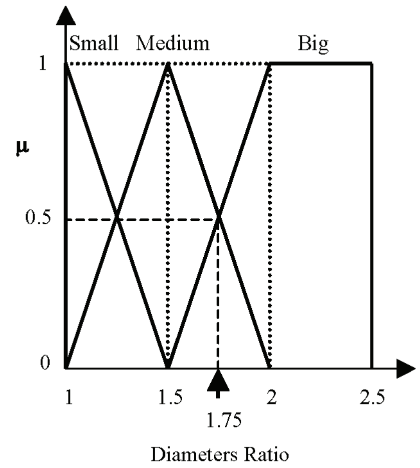


**Fig. 8.** Fuzzyfication of "Diameters Ratio".

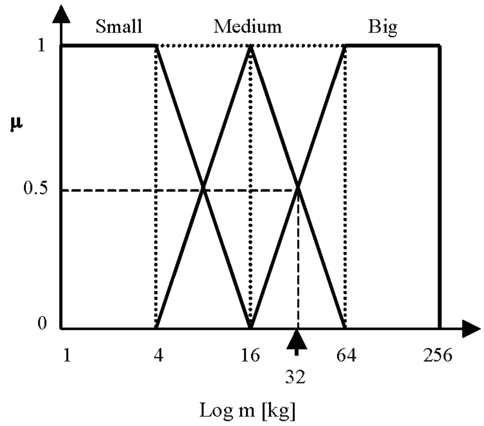


**Fig. 9.** Fuzzyfication of "Parts Mass".

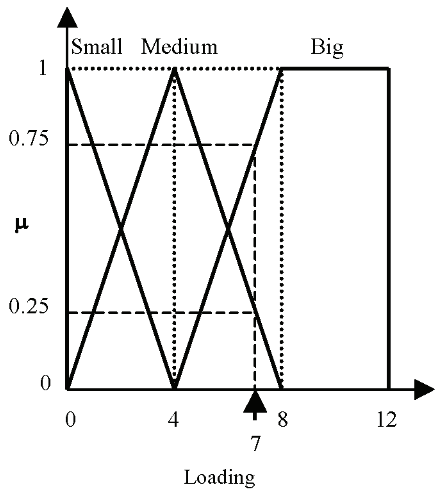


**Fig. 10.** Fuzzyfication of "Loading".

Table 2 presents all the 16 results of the inferences, which are computed as in the precedent example. The defuzzyfication by cumulative score gives:

$$\text{Score}_{Forged} = 0.75$$

$$\text{Score}_{Die} = 4.25.$$

*Table 2*

**Inferences results**

| | | | **Production volume** | |
|---|---|---|---|---|
| **Dia-Ratio** | **Mass** | **Load** | **Medium** | **High** |
| **Med.** | **Med.** | **Med.** | ***Die = 0.25*** | ***Die = 0.25*** |
| | | **Big** | Die = 0.50 | Die = 0.25 |
| | **Big** | **Med.** | ***Forged = 0.25*** | Die = 0.25 |
| | | **Big** | Forged = 0.50 | Die = 0.25 |
| **Big** | **Med.** | **Med.** | Die = 0.25 | Die = 0.25 |
| | | **Big** | Die = 0.50 | Die = 0.25 |
| | **Big** | **Med.** | Die = 0.25 | Die = 0.25 |
| | | **Big** | Die = 0.50 | Die = 0.25 |

So, close-die forged work pieces are recommended.

## 4. FURTHER RESEARCH

The further researches will consider the development of the algorithm in order to take into consideration more work pieces types and to refine the data formalization. The above-mentioned definitions of the linguistic variables are just proposals. Its definition must take into consideration the user experience. In order to simplify the algorithm application, a software program should be realized. There are some implementations of fuzzy logic routines in MATLAB. A new toolbox can be realized using the existing MATLAB toolboxes.

## 5. CONCLUSION

The paper describes a fuzzy logic based algorithm that is designed to formalize the choosing of the work pieces for arbors manufacturing. The proposed algorithm allows a rapid and better argued choosing of the work pieces in the products early design stage.

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