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A Fuzzy Monitoring System for an Extrusion Line

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Abstract

A monitoring system of an extrusion line was developed. Three main hydraulic pumps support the extrusion line in MODAL. Data of energy consumption was collected from the power supply of these main pumps. Clip-meters were attached to the supply wires in order to get the amount of the energy consumed; one reading is recorded every 5 seconds by a PC where the data is saved. The signatures of the billets extruded were studied to understand the signature behavior. Max-Min boundaries were found and a fuzzy system that makes use of the boundaries was built to indicate the unusual situations. The real on-line output is crisp and not fuzzy. It can be an alarm, a buzzer, a stop etc. The output is designed to give an approximate description of the situation in term of a percentage. The proposed system worked well in defining the real situation of the extruder. For future work, some recommendations were presented.

1. Introduction

1.1. Extrusion Process

Extrusion is one of the most popular metals forming processes used nowadays. The extrusion process involves forcing a billet, which is enclosed in a container, through an opening whose cross-sectional area and dimensions are smaller than those of the initial billet [1-5]. The cross section of the extruded metal will conform to that of the die opening. Principle of extrusion is shown in Figure 1.

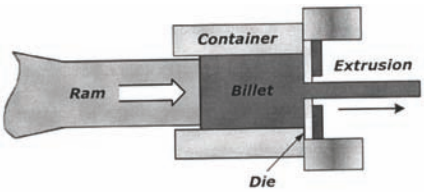

Figure 1: Principle of extrusion

Historically, extrusion was first used toward the end of the eighteenth century for producing lead pipes. It later gained widespread industrial applications for processing nonferrous metals and alloys like copper, brass, aluminum, zinc, and magnesium. Recently, with the modern developments in extrusion techniques, other metals like steel can be extruded.

Extrusion is the most used process in aluminum forming to produce different cross sections that used mainly in constructions like windows, doors frames, prefabricated houses structures and vehicles and aircraft parts and structures [6].

1.2. Fuzzy modeling

Fuzzy modeling is introduced as a practical alternative to conventional methods in solving modeling problems. Fuzzy system is recommended when a system without mathematical model or with high nonlinearity and uncertainty is to be modeled and controlled. Fuzzy system is simple in construction; it is simply a collection of linguistic IF_THEN rules. The rules can be obtained from an expert or by clustering input-output data [7]. In this paper the rules are developed through experience in extrusion process and by analyzing the data under consideration.

The Mamdani rule base is a crisp model of a system [8], i.e., it takes crisp inputs and produces crisp outputs. It does this with the use of user-defined fuzzy rules on user-defined fuzzy variables. Designing a Mamdani rule base requires three steps [8]: 1) determine appropriate fuzzy sets over the input domain and output range; 2) determine a set of rules between the fuzzy inputs and the fuzzy outputs that model system behavior; 3) create a framework that maps crisp inputs to crisp outputs. Fuzzy monitoring systems are considered in many applications in industry [9-12].

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2. Experimental Setup

In order to develop an energy monitoring system for the extrusion line in MODAL (**Mod**ern **Al**uminum Industries Company), a data of energy consumption is obtained by NERC (**N**ational **E**nergy **R**esearch **C**enter) according to the signed agreement between MODAL & NERC. Three main hydraulic pumps supported the extrusion line in MODAL; data were collected from the power supply of these main three pumps. Clip-meters attached to the supply wires in order to get the amount of the energy consumed, one reading is recorded every 5 seconds by a PC where the data is saved. Data of 11 different dies was collected. Table 1 shows the dies numbers and their specifications, while Figure 2 shows sample of obtained data. In Table 1, PH stands for Port-Hole type die and F is for Flat type die.

Table 1: Extruded dies and their specifications

Die No.	No. of billets extruded	Speed (mm/sec)	Production rate (Kg/hr)	Die Type	Extrusion ratio	Specific energy (KJ/Kg)
510240-2	42	6	1284	PH	53.8	289.8
IMO-1	41	9.2	1670	PH	45	269.7
2111-B	47	9	1570	PH	46.8	277.7
1059-SR-16	127	9.2	1535	PH	53.5	279.7
1059-SR-14	126	8	1568	PH	53.5	281.2
1021-SR-12	152	8.2	1192	PH	65.2	294
0329-1	26	5.1	1022	PH	78.1	323.9
600060-2	50	5	732	PH	90.4	360.5
1009-SR-14	57	10	1677	F	35	245.7
1008-SR-7	79	7.5	1414	F	52.6	270.7
1580M	43	7.1	970	F	72.8	321.9

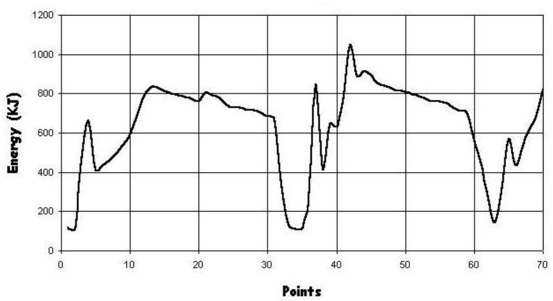

Figure 2: Sample of original data

For the die "1021 SR-12" 152 billets were extruded; two ideal maximum and minimum signatures are to be obtained. The aim is to predict unusual situations by monitoring energy consumption through the process of extrusion. For this die, the ideal extrusion speed was 8.2-mm/sec, billet length is 780-mm and ignoring the butt length, knowing that energy data was recorded every 5 sec; the expected number of readings for each billet can be computed by:

Time for each billet = billet length / extrusion speed

= 780 / 8.2 = 95.122

Number of readings for each billet = Time / time-interval

= 95.122 / 5 = 19.024 $\cong$ 19-reading.

The obtained actual number of readings is different from the ideal; Table 2 shows that billets have different extrusion time due to variation in extrusion speed. From the table, 28-billets have 27 readings and 20-billets with 26 readings; therefore, 27 readings can be used to investigate the energy consumption behavior.

Table 2: Number of billets of the same number of points

Number of points	Number of billets	Number of points	Number of billets
17	1	27	28
19	1	28	10
20	1	29	10
21	3	30	8
22	6	31	7
23	19	32	1
24	17	33	3
25	15	43	1
26	20	44	1
		All	152

3. Data Analysis

The data of the 28-billets of 27-points is used to estimate the max-min boundaries; the data of 25, 26, 28 & 29-points is modified to 27-points. First of all, the modification needs a good understanding of the signature behavior. Figure 3 shows one of the 28-billets, the signature starts at point 1 and reaches the 1st UP (upper-peak) at point 3, then it goes down to 1st LP (lower-peak) at point 4. The signature then goes up to 2nd UP at point 11. After the last peak, the signature goes down linearly to point 23, where the knee starts and it ends at point 25. The last peak, 3rd UP, occurs usually at point 26 and some times at point 25. Point 27 is the end point.

Figure 3: Sample signature of 27-points

We can clearly note that the modification can be applied to the linear region with no effect on the general scheme of the signature. Some modification can be applied to other regions to get close to ideal signature. Finally, 70 billets were modified; Table 3 shows 4 samples of the four modified ones.

For unmodified billet-58 of 25-points in Table 1, two points are added. The first one is the average of points 14 & 15 and it is inserted between them. The second one is inserted in the same way between points 19 & 20. Billet-100 of 26-points is modified like Billet-58 and one point is inserted between points 14 & 15. On the other hand, billet-15 of 28-points is modified by deleting point 15, and billet-18 of 29-points is modified by deleting points 2 & 14.

Table 3: Sample-modified signatures

Point No.	Billet-58 original	Billet-58 modified	Billet-100 original	Billet-100 modified	Billet-15 original	Billet-15 modified	Billet-18 original	Billet-18 modified
1	113	113	143.5	143.5	100.5	100.5	248.5	248.5
2	238.5	238.5	606	606	252.5	252.5	266	414.5
3	1115	1115	581.5	581.5	485.5	485.5	414.5	793.5
4	790.5	790.5	466.5	466.5	404	404	793.5	655.5
5	622.5	622.5	548	548	550	550	655.5	788.5
6	693.5	693.5	666.5	666.5	706.5	706.5	788.5	936.5
7	793.5	793.5	775	775	785	785	936.5	1043.5
8	904.5	904.5	887	887	1144	1144	1043.5	910
9	1090.5	1090.5	1070	1070	1054.5	1054.5	910	886
10	1054.5	1054.5	1118	1118	880.5	880.5	886	866.5
11	1016.5	1016.5	1065	1065	875	875	866.5	856.5
12	1037	1037	1060	1060	849.5	849.5	856.5	845.5
13	991.5	991.5	1032.5	1032.5	847.5	847.5	845.5	801.5
14	978	978	1007	1007	832	832	772.5	792
15	959	968.5	982	994.5	847.5	807	801.5	778
16	945.5	959	968.5	982	807	778.5	792	767
17	921.5	945.5	946	968.5	778.5	773.5	778	753.5
18	904.5	921.5	923.5	946	773.5	765.5	767	739.5
19	890	904.5	888.5	923.5	765.5	751.5	753.5	731.5
20	865	890	887	888.5	751.5	736	739.5	714
21	837.5	877.5	858.5	887	736	722	731.5	700.5
22	813	865	609	858.5	722	687.5	714	661
23	659.5	837.5	439.5	609	687.5	709	700.5	463
24	960	813	427	439.5	709	646	661	387
25	114	659.5	254	427	646	463	463	750.5
26	-	960	165.5	254	463	691.5	387	240.5
27	-	114	-	165.5	691.5	131.5	750.5	104
28	-	-	-	-	131.5	-	240.5	-
29	-	-	-	-	-	-	104	-

3.1. Estimating the max-min boundaries

Some of the real world distributions are normal; consider the values at each point to be distributed normally. Then, the boundaries of random sample from a normal distribution with $(1-\alpha)\times 100\%$ confidence interval will be:

min < μ < max

$$x' - \frac{t_{\alpha/2} \times s}{\sqrt{n}} < \mu < x' + \frac{t_{\alpha/2} \times s}{\sqrt{n}}$$

where:

x' = sample mean

N = number of samples

$t_{\alpha/2}$ = t-value from t distribution table with $v = n - 1$ degrees of freedom, leaving an area of $\alpha/2$ to the right.

s = standard deviation;

$$s^2 = \sum_{i=1}^{n} \frac{(x_i - x')^2}{n-1}$$

In our case we have n = 70 and α = 0.01 to get 99 % confidence interval. The max-min boundaries are shown in Figure 4. Based on the boundaries, the building process for the fuzzy system can begin.

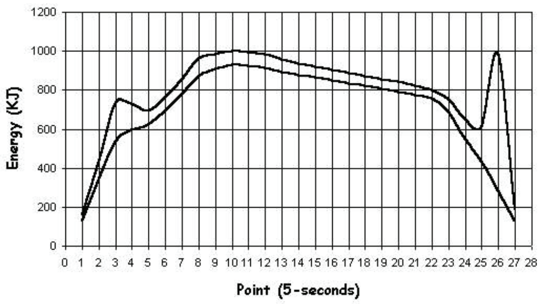

Figure 4: max-min boundaries

3.2. Fuzzy System

First of all, inputs and outputs of the system must be identified. In our case, we have two inputs (Region & Error), and one output (Situation). Figure 5 shows the standard deviation of the samples at each point of the 27-points this figure is needed in input-output identification.

1st Input: Region

From Figure 5, we can divide any signature into 3-Regions. The crisp regions are:

R1 : points from (1) to (5)

R2 : points from (5) to (22)

R3 : points from (22) to (27).

The fuzzy membership functions are shown in Figure 6.

2nd Input: Error

To indicate if the input signature exceeds the max-min boundaries or it is within range, the following input is defined as:

Error = min(max_value – input_value, input_value – min_value)

This min. function produces the error input. If the input signature exceeded any boundary, a negative input error is produced and if the input signature is within range, the input error is positive.

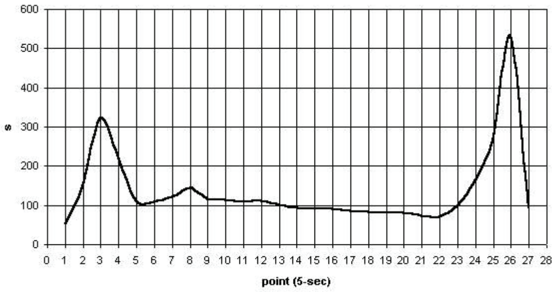

Figure 5: Standard deviation of samples

Fuzzy membership functions for the Error are shown in Figure 7. These functions are as follows:

In_range : +ve error is produced
e : accepted –ve error is produced
ee : significant –ve error is produced

The Output: Situation

The real on-line output is needed to be crisp and not fuzzy. It can be an alarm, buzzer, stop etc.; the output is designed to give an approximate description of the situation in term of percentage. The output membership functions are shown in Figure 8; the situations were selected logically to be:

Normal: nothing unusual, the situation is OK
Be_careful: keeps attention about the situation
Problem: a problem occurred

Fuzzy System Rules:

Typically, the number of rules is the product of the number of the membership functions of each input. In our case, the number of rules supposed to be 3*3 = 9-rules, but 7-rules were written for this system. The rules are:

IF (Error is in_range) **THEN** (Situation is Normal)
IF (Region is R1) and (Error is e) **THEN** (Situation is Normal)
IF (Region is R2) and (Error is E) **THEN**(Situation is be_careful)
IF (Region is R3) and (Error is e) **THEN** (Situation is Normal)
IF (Region is R1) and (Error is ee) **THEN** (Situation is be_careful)
IF (Region is R2) and (Error is ee) **THEN** (Situation is Problem)
IF (Region is R3) and (Error is ee) **THEN** (Situation is be_careful)

The first rule cancels two rules, because in_range signature in any region is safe and then the situation is normal. For regions R1 & R3 a high standard deviation can be noted and this means that the prediction is highly uncertain. Region R2 is a stable region with low standard deviation. Therefore, any significant value for error indicates, mostly, a problem.

3.3. System Examination

To examine this system, a billet of 24-points was modified to 27-points as explained above. Table 4 shows the signature and its evaluation according to the proposed fuzzy system. We can conclude from this table that the signature is within limits and there is nothing to worry about. The maximum number in the evaluation column is 50 which mean means the situation is normal or be careful according to Figure 8.

Table 4: Evaluation of the signature of billet 50

point	Billet 50	Billet 50-evaluation	point	Billet 50	Billet 50-evaluation	point	Billet 50	Billet 50-evaluation
1	116	20.3659	10	1027.5	34.7335	19	856	19.1842
2	239	19.1842	11	1013	30.5996	20	846.5	21.0078
3	962.5	50	12	998.5	28.4504	21	816	19.1842
4	759	21.6239	13	957	19.1842	22	798.5	19.1842
5	758	19.1842	14	931.5	19.1842	23	751.5	19.1842
6	879.5	26.9787	15	945.5	33.7021	24	629.25	19.1842
7	965.25	34.2143	16	917.5	26.9787	25	507	50
8	1051	41.5449	17	888.5	19.1842	26	1278	50
9	1012.5	37.0964	18	863	19.1842	27	211.5	21.4578

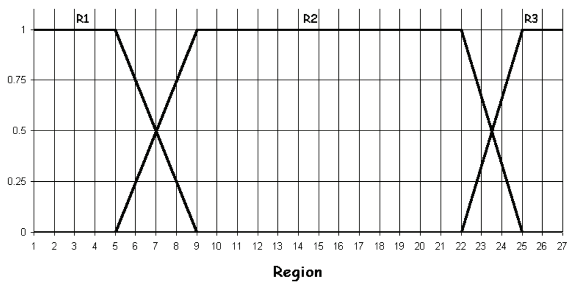

Figure 6: Membership functions for "Region" input

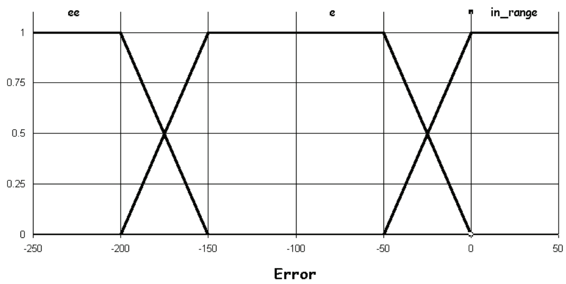

Figure 7: Membership functions for "Error" input

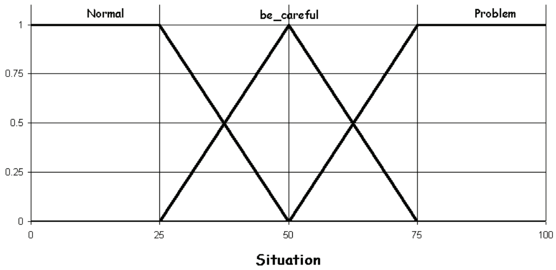

Figure 8: Membership functions for “Situation” output

4. Signature Behavior

In order to explain the signature behavior, the average of the 70 billets will be examined in Figure 9. In the first going up part of the signature, the heated billet is compressed and fills the clearance between the billet and the container by caused lateral strain. In the second going up part, a metal flow is going to overcome the static friction between the billet and the container,as well as between the metal and the die.

In the going down part in the mid of the signature, the friction becomes dynamic; the size to be extruded get decreased and the billet is heated up by the friction between atoms. The energy decreased semi-linearly. The peak at the end of the signature can be related to the impurities increasing, so the remaining metal becomes harder and stronger.

The extrusion process internally is a flow of atoms on each other. The slipping on the planes that contains impurities is harder than other pure planes and thus needs more energy. The whole signature behavior can be simply related to this principle, so that the composition of the billet and the distribution of impurities may affect the behavior.


Figure 9: The average of the 70-signatures

5. Conclusions

In this work, a monitoring system of an extrusion line is developed; a data of energy consumption is collected. The signatures of the billets extruded are studied to understand the signature behavior. Max-Min boundaries are found and a fuzzy system that makes use of the boundaries is built to indicate unusual situations. The real on-line output is crisp and not fuzzy. It can be an alarm, buzzer, stop etc.; the output is designed to give an approximate description of the situation in terms of percentage. To examine this system, a billet of 27-points is chosen. The signature has been evaluated according to the proposed fuzzy system. The proposed system works well in defining the real situation of the extruder.

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