DETERMINATION OF CRYSTALLIZER SERVICE LIFE ON CONTINUOUS STEEL CASTING BY MEANS OF THE KNOWLEDGE SYSTEM

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Abstract: In this paper there is described the input analysis of the crystallizer service life control problem for creation and exploitation of the software product in order to apply the knowledge systems complemented by the continuous diagnostics that will significantly reduce the human factor involvement in providing the manufacturing equipments inspection, in identification of technical condition and failures of equipments, specification of failures prediction and possibly also in failures elimination through a partial or total automation.

Keywords: Knowledge system, fuzzy systems, prediction, reliability, lifetime, steel industry.

1. Introduction

A full exploitation of continuous casting equipment (thereinafter ZPO) advantages can only be achieved through a control system that minimizes all undesirable effects on the technological process. Some of the undesirable effects influencing the ZPO process effectiveness are the failures and service interruptions. The failures and service interruptions are caused by a number of factors, impacts and processes that effect and run directly on the equipment in its individual parts during its operation[1]. These impacts result in changing the characteristics of equipment and its parts functional faces and they are the primary technical reasons for the failures affecting the process effectiveness and the service life of individual parts. These effects often have a vague character and their correction will no longer be managed in a traditional way of addressing the problem of technological systems service life control.

2. Technological Systems Service Life

The technological systems service life control includes the process and its control when we determine the period of time during which the equipment or its parts are able to perform the required function under given conditions of use and maintenance up to the moment when the limiting state has been achieved. When dealing with this problem it is necessary to be aware of the fact, that the meaning of service life term varies in various stages of equipment life cycle, therefore we must distinguish the terms as follows [2]:

- Planned technical life = the period of time determined by the designer, during which the equipment has to be able to perform safely and reliably its function; all economic evaluations and as a rule also the permitting procedures are related to the planned technical life (In principle the planned technical life is shorter than the rated technical life of the equipment);
- Rated technical life = the minimum period of time during which the equipment or its parts must be able to perform safely and reliably their functions under given conditions; this time is determined by means of calculation methods;
- Technical life = the period of time on the expiry of which the limiting state occurs (the technical life is always longer than the rated technical life);
- The total life = the maximum achievable service life of an equipment that is terminated by the final retirement of the equipment based on the limiting state;

- The residual life = the period of time during which the technology(or the equipment) can be operated with the required reliability; it is the time left until the technical life or the total life of the equipment have been reached.
- Limiting state = the technical state of the equipment during which the further use of equipment must be interrupted due to an irremovable infringement of safety requirements, irremovably exceeded limits set for parameters, irremovable decrease of operation effectiveness below the admissible level or due to an overhaul execution.

The graphical interpretation of above terms is shown in Fig. 1.

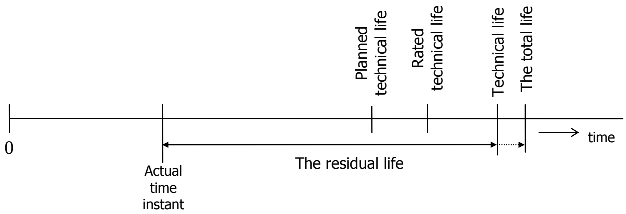


Fig. 1 The graphical interpretation of service life terms

3. Crystallizer Service Life

The crystallizer is one part the ZPO that significantly influences the continuous cast blank (thereinafter PLP) quality both in view of the internal structure and the surface purity and the dimensional accuracy. The crystallizer service life is influenced first of all by its wear. The physical mechanism of crystallizer wear can be described as follows:

If the surfaces of two functional faces (liquid steel or slightly solidified PLP crust and the crystallizer walls) near by virtue of the self-weight of steel/PLP or the oscillatory mechanism there occurs the first contact theoretically in three points. In these points the real surface pressure is as big as to cause the plastic deformation and parts of surface breaking off (this all in microscopic dimensions). Consequently other places on the parts surface are contacted. On these parts the same processes are running as long as the real contact surface has achieved the level when the real surface pressure does not induce any other deformations. Obviously the achievement of this equilibrium state depends on more factors. For a better description of crystallizer surface wear mechanism it is possible to base it on a general model of the metal polished component surface layer (see Fig.2).

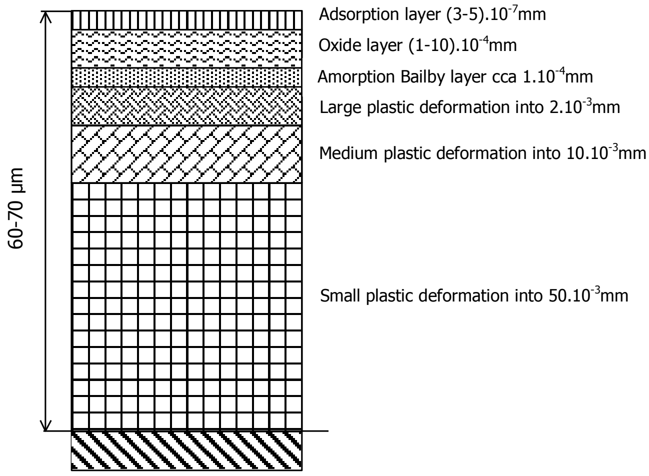


Fig. 2 Schematic cross section of the polished surface [3]

When nearing the surfaces the integrity of the adsorption layer and the oxide layer gets destroyed and consequently the surfaces get into the metallic contact. This results in micro-joints formation. When they are subsequently destroyed due to the relative movement of surfaces the metallic components become separated and the surface material gets displaced. The intensity of this process depends on many factors and the most important of them are as follows [3]:

- The kind and the characteristics of mutually acting surfaces of bodies;
- The presence and characteristics of the medium between the surfaces;
- The characteristics of a relative motion of surfaces (direction, speed, their time changes);
- Load (the size of acting forces, their time changes).

When applying this principal model of wear to the crystallizer it is necessary to supplement the above factors by the effect of process temperature factors.

The basic material used for the crystallizers manufacture is the copper (electrolytic copper deoxidated by adding the phosphorus) .This kind of crystallizer is used thanks to its low acquisition costs and a good heat removal plus a high heat convection ability. Lately it has been found that it is more suitable to use the copper alloys with other metals like the chromium or zirconium Cu–Cr (0,5 up to 0,8%) or Cu–Cr–Zr (0,7% Cr, 0,6 % Zr). This reduces the heat conductivity but at the same time the crystallizer service life is growing. The PLP characteristics are given by the chemical composition of the cast steels.

According to the cast PLP format we distinguish two basic kinds of crystallizers: the tube and plate crystallizers. The tube crystallizers have the thickness of walls between 6 and 10mm and during their lifetime they only can be lightly cleaned twice. In case of the plate crystallizers the thickness of wall can achieve up to 50mm. The crystallizer plates during their service life can be machined several times down to 15 mm wall thickness. The crystallizers for ZPO are characterized by a crosscut, slant of walls, length and shape of edges.
The crystallizer service life is generally solved per the footage of the steel cast in a given crystallizer, the total steel mass or number of cast heats. When related to the heats we can expect the values between 100 and 2500. A big difference is given by a different volume of ladle and PLP cross-section. If we relate the crystallizer service life to meters under normal operation conditions we can ensure the cast of 10-15thousands of PLP meters. In the submitted recommended solution there is used the diagnostic signal of the cast steel weight. [6]
The crystallizer exchange depends on its surface or the corner joints condition. These joints opening must be less than 0,3mm, otherwise the surface defects occur. The wear of the lower slant is another factor influencing the crystallizer service life. If this exceeds 1,5 to 2 mm at the slab wear and 0,7 mm at the blocks wear then in case of blanks there occur the edge cracks thus a low quality production.
The operation experience enables us to define following effects impacting the crystallizer service life and the possibilities to influence them during the casting process. [7,9]

- The properties and the quality of crystallizer material-these properties are explicitly given by the manufacturer of the crystallizer insert therefore they cannot be influenced during the casting process.
- The shape and size of the continuously cast blank (only PLP hereinafter) – these parameters are important for calculation of the cast steel mass; the parameters are given by the type of crystallizer, they cannot be influenced during the casting process.
- The way of cooling– it can be influenced, but the way of cooling is given by the technological parameters and is controlled with regard to the casting process technological effectiveness, not in view of crystallizer wear,
- The casting speed – it can be influenced during the casting process, but the same argument as at the way of cooling applies,
- The operational effects (inaccurate centring of immersion nozzles related to the metallurgical axis, casting in a turbulent flow, casting with too low temperature or with a too high aluminium fraction in steel) – some of these impacts can be influenced, but in general there are also preferred the technological and not only the maintenance aspects.

The above facts show that the crystallizer service life maximization is given by mutual combination of construction- technical, operational and organizational parameters that always are related to the concrete equipment.

3.1 The Board Crystallizer of the Size 300x350

Parameters of board crystallizer:

type	with solid gauge boards
cross-section (mm)	300 x 350
height (mm)	700
radius of the rear wall (m)	14
position relative to the axis of oscillation (mm)	
▪ **upper position**	+400
▪ **lower position**	
coppery boards	
▪ **quality**	copper + silver
▪ **hardness**	Brinell HB 80
conicalness	convergency down
fixturing of coppery boards	using rods and spring washers
total weight of 1 crystallizer (kg)	2815

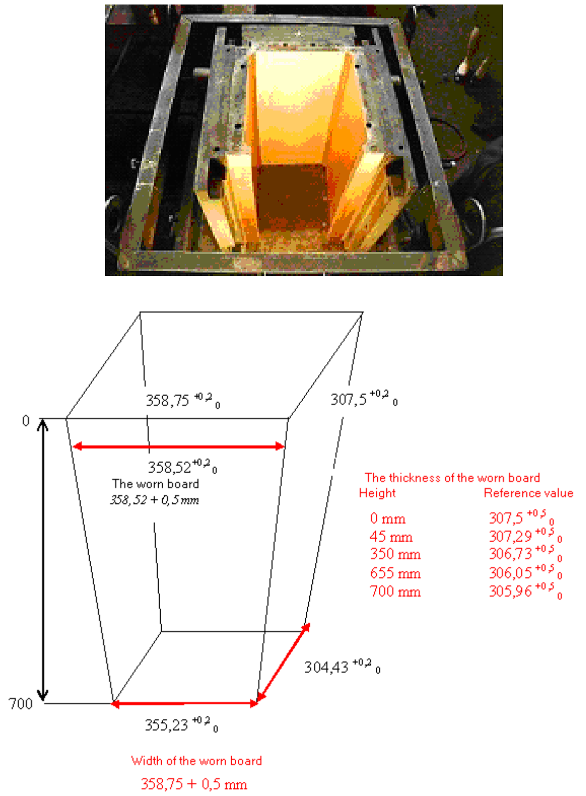


Fig. 4 Limiting size of board crystallizer [4]

The play between small and big walls

- the check is carried out by the gauge throughout the depth in each of the four corners
- reference value for new or refurbished boards J ≤ 0,1 mm
- reference value for worn board before renewal J ≤ 0,3 mm
- plumb of small and big walls
- the check by the squares and the gauge in the same places like in the measurement of width
- reference value for new boards P1 = ± 0,2 mm
- reference value for refurbished boards P1 = ± 0,5 mm
- reference value for worn boards before refurbished P1 = ± 1,0 mm

Parallelism of big walls

- it is measured in the same point like in the measurement of width
- reference value for new boards P = ± 0,2 mm
- reference value for refurbished boards P = ± 0,5 mm
- reference value for worn boards before refurbished P = ± 1,0 mm

The width of upper and lower part (in the Fig. 4)
The thickness of upper and lower part (in the Fig. 4)

3.2 The measuring system MKL 100/420

Currently, the measuring system MKL 100/420 of DASFOS Company, v.o.s. is used for operating measurement of the walls of crystallizer. In terms of the solution the data obtained from the made operational measurements were used. The measuring system MKL 100/420 is a portable measuring instrument (the technical parameters are noted in Table 1) which is configurable according to a measurable format, equipped with control electronics and a basic software for operating of measurement and basic data processing and it has the following basic elements [12]:

Clamping mechanism: individual for every measured proportion. It ensures the fixation of measuring part in the slot of crystallizer, its orientation toward the direction of pouring, and keeps it in the measuring position.

Measuring part: the base of this part is non-contact laser meter of distance located on the exact mechanical line. Before the measurement the calibration is done, using the reference length of measured in clamping mechanism. The measuring is done at five positions for every board of crystallizer of the rectangular cross-section.

Control electronics: the industrial computer MiniPanel PPC-55 with coloured STN LCD screen creates the base. The small membrane keyboard serves for setting the basic accompanying data to the crystallizer. The self measurement is in progress according to the specified algorithm fully automatically. The software of control electronics within the self measuring does the process of measured data, on the screen it displays the basic information about the taper of crystallizer for every zone of bevel and comparing with previous measurements.

The measurement of board attrition of crystallizer is done at 5 points on every board of crystallizer in the coordinates -135, -70, 0, 70, 135 for big walls and in coordinates -108, -60, 0, 60, 108 for side walls and in 18th surfaces of height of crystallizer (27, 66, 105, 144, 183, 222, 261, 300, 339, 378, 417, 456, 495, 534, 573, 612, 651, 690mm).

The coordinates on the boards are illustrated in the Fig. 5 in which the measurement is in the progress. The distance between the median axis and its parallel wall of crystallizer is counted.

Table 1 Technical parameters of the MKL 100/420 system

Title:	Non-contact laser measurement
Variable range:	150 – 450 mm
Distinction:	6µm
Range of depth measurement:	0 - 800 mm
Accuracy of setting up the level of measurable surface:	+/- 0,1 mm
Incoming supply:	220V , 80 VA
The size of control unit with the bag:	390x220x160 mm
The size of mechanism:	220x220x160 mm
Weight:	c. 12 kg
Data transfer:	standard line, optionally infra
Operating system of measurement:	MS-DOS 6.22
Operating system of visualization and processing of data:	MS Windows

The measurable values of attrition by the measuring system MKL 100/420 of DASFOS, v.o.s. company and the designed system of attrition visualization were used for primary analyse of crystallizers lifetime (vide chapter 3.1). The results (vide Fig. 6) and the follow-up counsel with operational workers confirmed the problems about the quality of PLP in the connections of crystallizer boards in the form of PLP breaches.

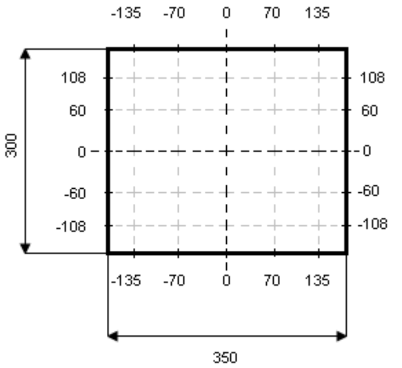
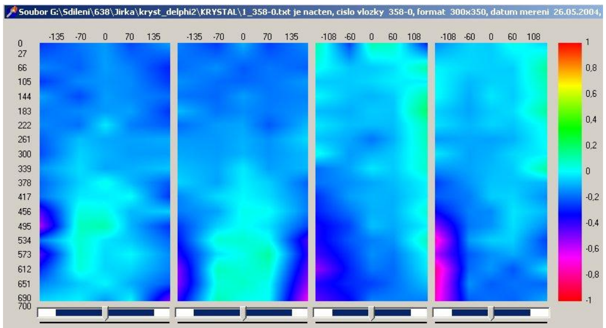
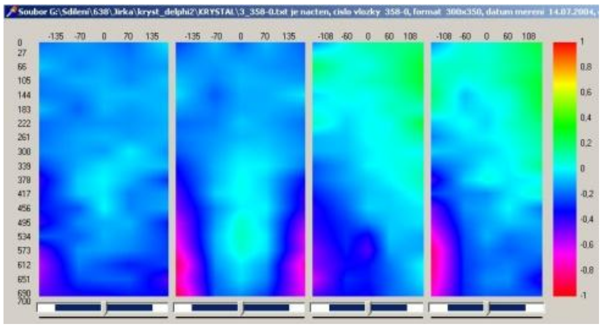


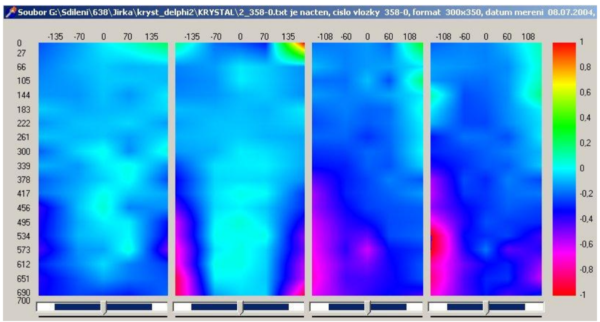
Fig. 5 The coordinates of measurement of the wall attrition (the top view on the crystallizer)



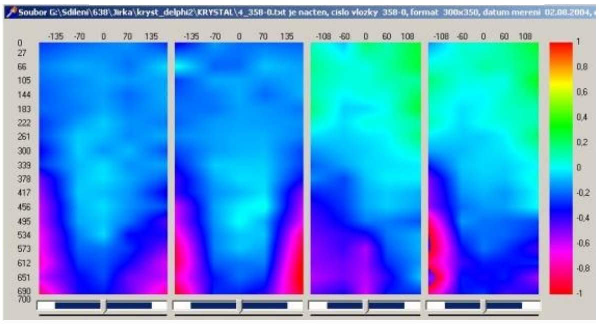
2539 tons were poured



3192 tons were poured



5960 tons were poured



11790 tons were poured

Fig. 6 The example of attrition analysis in the process of technical life with the usage of visualization system

4. Reliability Analysis of Board Crystallizer

The origin of the limit state object is caused by many factors of influences and processes that react and proceed right on the object, to its individual parts, during its operation. These influences have resulted in changes of qualities of functional surface of an object and its parts and they are the primary technical symptoms of the origin of the limit state which affect both the efficiency of the process but also the object lifetime. On principle the limit state is given by the sum of particular states during the technical lifetime of the object.

In term of the theory of reliability we can consider the crystallizer as non-renewal object. The statistical and probabilistic analysis of the technical lifetime of the crystallizers is the first move in solution. Within this analysis 23 crystallizers were examined on which the measurements of attrition of MKL 100/420 machine from DASFOS, v.o.s. company were done in the process of their technical lifetime.

The following statistics were provided

The middle poured amount of steel during the technical lifetime of crystallizers	12338,69 tons
Selective standard deviation	1090,95 tons
Selective dispersion	1190173,49 tons
The variation coefficient	0,088417022¨

The value of the variation coefficient with the usage of Table 2 confirms the prior presumptions that the mechanism of the limit state of crystallizer is caused by the attrition of material. The value of the variation coefficient with the usage of Table 3 shows that the random quantity will show a normal division of probability, which below the histogram in the Fig. 6 documents. However, for versatility of solution for other solutions the normal division of probability of random quantity will not be used, it will be reaplaced by Weibull division of probability of random quantity which allows the approximation of a normal division using its parameters. It ensues from Table 3 that for the calculated variation coefficient the value of the parameter of the shape of Weibull division of probability will be close to the value 10.

Table 2 Defined mechanisms of failure on the base of the value of variation coefficient

Value of variation coefficient	Mechanism of failure
0,010 ÷ 0,050	fatigue of material
0,050 ÷ 0,150	attrition of material with the elements of material fatigue
0,150 ÷ 0,700	attrition and corrosion
0,700 ÷ 0,900	material ageing with beginning marked symptom of corrosion and attrition
0,900 ÷ 1,000	material ageing
1,000 >	failure from the constructive or technological mismanagement

Table 3 Relation of variation coefficient, parameter of the shape and division of probability

Value of variation coefficient	Value of the shape parameter	Division of probability
0,010 ÷ 0,050	> 10,00	logarithmically-normal division
0,050 ÷ 0,700	10,00 ÷ 1,50	normal division
0,700 ÷ 1,000	1,12 ÷ 0,90	Exponential division
> 1,000	<0,90	Weibull division

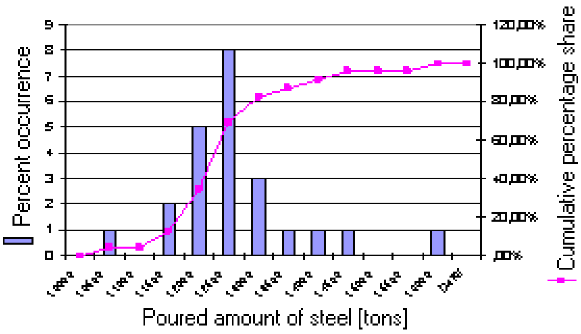


Fig. 6 Histogram of the technical lifetime of crystallizers

We get the parameters of Weibull division of probability through the solution of the relation 1 and 2, that is

$$\frac{\sum_{i=1}^{n} t_i^{\overline{m}} \cdot \ln(t_i)}{\sum_{i=1}^{n} t_i^{\overline{m}}} - \frac{1}{n} \cdot \sum_{i=1}^{n} \ln(t_i) - \frac{1}{\overline{m}} = 0 \qquad (1)$$

$$\hat{\lambda} = \frac{n}{\sum_{\forall i} t_i^{\overline{m}}} \qquad (2)$$

where $\overline{m}$ point estimate of parameter of the shape of Weibull division,

$\hat{\lambda}$ point estimate of reverse value of parameter of gauge of Weibull division,

n number of observing,

t_i value of i^{th} observing of random quantity of t.

Following parameters of Weibull division were got by the numerical solution

parameter of the shape m 10,316

reverse value of the gauge parameter $4{,}09 \cdot 10^{-43}$

We got the course of the distribution function of Weibull division of probability of random quantity through the instalment these values to the relation 3 (vide Picture 7)

$$F(t) = 1 - e^{-\frac{t^m}{t_0}} = 1 - e^{-\lambda \cdot t^m}. \quad (3)$$

The distribution function thus obtained was compared with the empirical distribution function obtained from measured values of the technical lifetime of the crystallizers (vide Fig. 8) and the examination of validity of the obtained distribution function with usage of the Kolmogorov-Smirnov test of the congruity for one selection was done. The test on the surface of significance 0,01 and 0,05 confirmed that the obtained distribution function with Weibull division of probability describes the measured data of the technical lifetime of crystallizers.

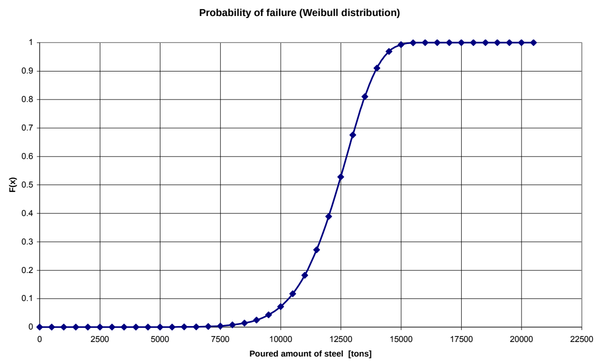


Fig. 7 Course of a distribution function

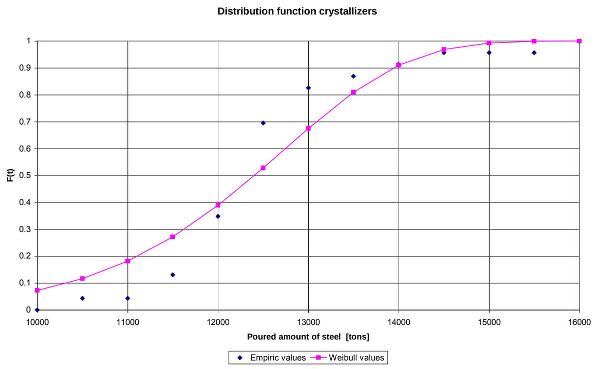


Fig. 8 Comparing of measured data and obtained distribution function

The middle period of the technical lifetime of the model 12603,67 tons

The results of the analysis shows that by the 78,26% of the surveyed crystallizers even the average technical lifetime has not been reached, even 55,83% of their technical lifetime.

The causes of this state can be found in the following reasons:

- human factor;
- crystallizer is extremely stressed owing to any of the above influences in chapter 3 or by virtue of more influences at once and thus leads to its increased attrition and thus shortening the technical lifetime.

5. Setting the Service Life By Using the Knowledge Systems

The actual research in the service life of the technical systems shows, that the given problems represent a complicated multi-parametric task which often exceeds the limits of traditional mathematic analytical & statistic methods. These are based on objective quantitative knowledge it means the knowledge of physical principle and mathematical description of modelled and controlled systems. The behaviour of such a model isn’t always identical with the behaviour of a real system that includes the uncertainty and contingency elements. The mathematic statistics is one of the possible ways of uncertainty description. But this is restricted by its ability to describe just the stochastic uncertainty, often with number of observations insufficient for a good quality statistic model and with problems of a precarious presumptions validity. It all results in increased demands on accuracy and amount of input data and an increased model complicacy. Such a model in its demands can exceed the limit when it is still

practically feasible, which complies with the incompatibility principle [5]:
„Just as the complicacy of a system grows, there drops our ability to issue the precise and still usable statements about the systems behaviour, until the threshold has been reached behind which the preciseness and usability become almost exclusionary characteristics ."
Therefore in compliance with modern trends in the control area for such a task it is suitable to use the knowledge systems.

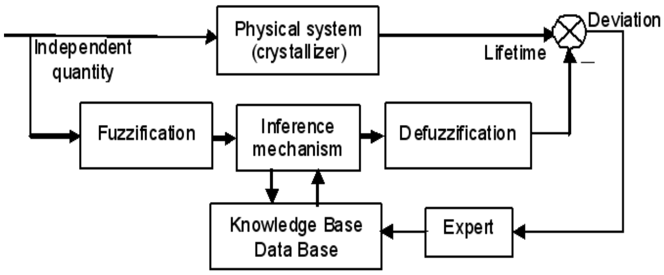


Fig.3 Principle for determining of lifetime of knowledge system

The principles of this approach consist in the use of knowledge based not on the validity of objective and qualitative knowledge but on the human experience it means on subjective heuristic knowledge. These methods use the same principles for construction of effective model structures as a human expert uses including the conceptual uncertainty. This results in unconventional non-numerical linguistic models. It is proved that these systems applicability in compliance with above incompatibility principle exceeds the limits of conventional mathematic- analytical models. [8]

5.1 Basis for solution (precarious knowledge)

In general it applies that at the crystallizers with small cross-sections the wear is faster due to higher casting speeds. [11,12]

- Also the curved crystallizers show a shorter service life, which is caused by an eccentric impact of the cast flow into the crystallizer and a higher mechanic abrasion in the lower part of crystallizer.
- It applies that the crystallizers with small cross-sections get deformed less than the crystallizers with large cross-sections and the crystallizers with rectangular cross-sections get deformed less than those with square cross-sections.
- If in case of a slab ZPO the wear is greater than 1,5 - 2,0 mm on the lower part and in case of a block ZPO it is 0,7 mm, then depending on the assortment at the blanks occur the corner cracks thus the low quality products.
- The low temperatures and the pressure changes transferred by the solidified crust in the lower part of the crystallizer do not allow to keep the same conditions of the hydrodynamic lubrication. Currently it is impossible to create a secure imagination about the slag behaviour in this area. At some places there occurs a solid friction between the solid substances. When the copper surface of the crystallizer is smoother that the steel solidified crust surface then it is very probable that the pieces of solidified slag or highly viscose slag progress together with steel when it is falling. Before leaving the crystallizer the steel surface temperature can drop so much, that the slag behaves like a solid substance also when contacting the solidified crust. Then at the interface between the solid slag and the copper of crystallizer occur the slips and erosion of crystallizer copper surface. [10]

The principle of solution can be described as follows: The inception of an equipment limiting state is effected by several impacts and processes that work and run directly on the equipment and its individual parts of the during its operation. These effects result in changing the characteristics of some functional faces of the equipment and its parts and they become the primary technical signs of the limiting state inception influencing both the process effectiveness and the equipment service life. The suggested algorithm consists in evaluation of the crystallizer wear exposure at individual process stages in casting the individual heats at the moments of measuring the technological parameters in casting process. The individual risks are used for calculation of relative frequency and cumulative relative frequency in individual wear risk categories, that constitute the inputs into other expert system in which there is determined the parameter of Weibull distribution shape. This parameter is then applied to the distribution function of the crystallizer total physical life based on the Weibull distribution, from which there is calculated the spot estimation of the total cast steel mass and subsequently the spot estimation of the mass cast up to the technical or the total life achievement(extinction) , which is the result of the particular solution. This principle is illustrated in Fig. 4.

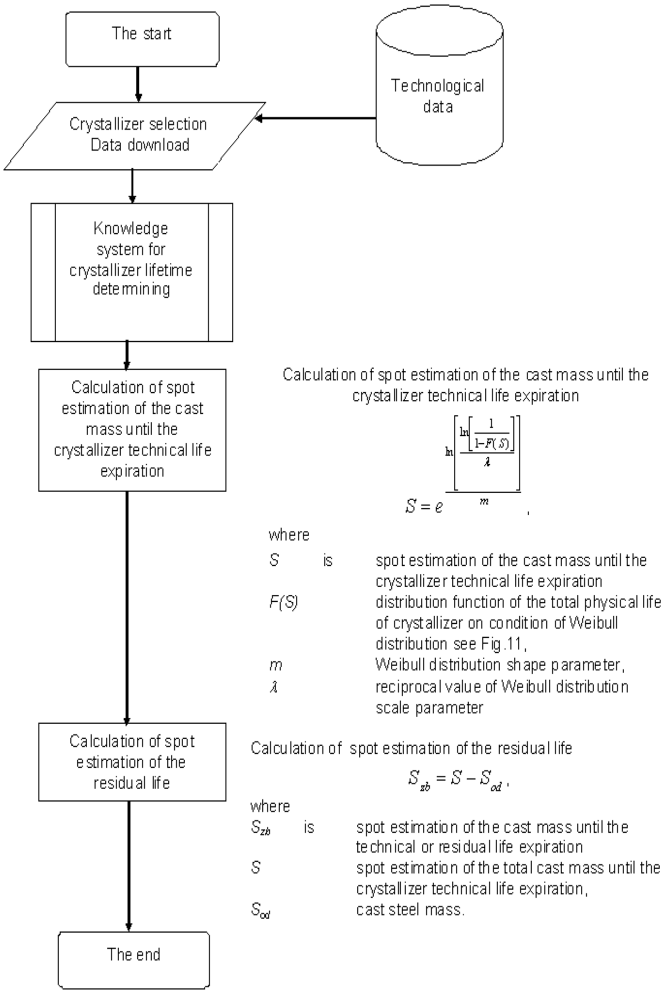


Fig. 4 Algorithm of residual service life determination

5.2 Determination of wearing risks of crystallizer in during melting

Parameters:
Number of variables: 4 (Fig. 5)

Independent variables

- Casting speed
- Overheating above the liquid temperature
- Aluminium content

Dependent variable

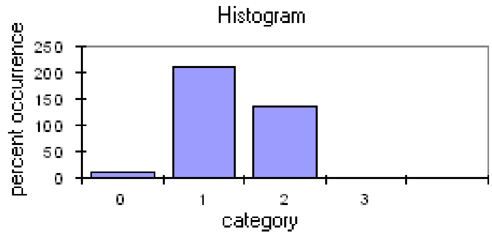
- Risk

Name	I/O	Type	Weight
Overheating above the liquid temper...	Input	Integer	100,00
Casting speed	Input	Real	100,00
Aluminium content	Input	Real	100,00
Risk	Output	Enumeration	100,00

Fig. 5 System parameters

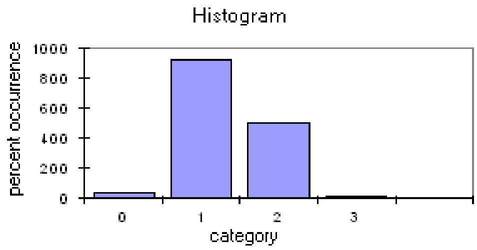
Result examples in current time period

1. interval



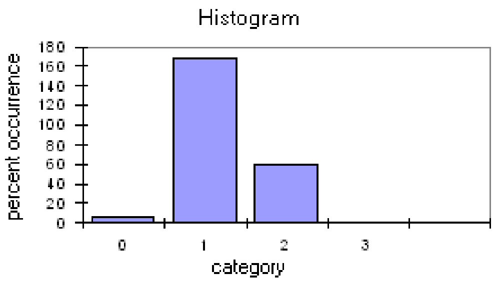
Category	Percent occurrence
0	10
1	211
2	137
3	0

2. interval



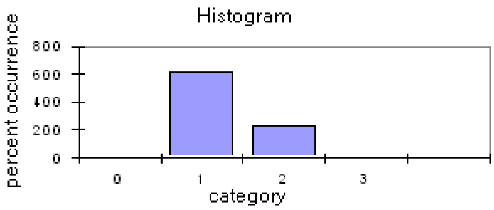
Category	Percent occurrence
0	37
1	928
2	508
3	16

3. interval



Category	Percent occurrence
0	6
1	168
2	60
3	0

4. interval



Category	Percent occurrence
0	15
1	614
2	236
3	0

5.3 Knowledge system for crystallizer lifetime determining

Expert system parameters :
Number of variables : 5 (Fig. 6)
Independent variables

- Low risk relative frequency (Fig. 7)
- Medium risk relative frequency
- High risk relative frequency
- Cast mass

Dependent variables

- Weibull distribution shape parameter

Name	I/O	Type	Weight
Low risk relative frequency	Input	Real	100,00
Medium risk relative frequency	Input	Real	100,00
High risk relative frequency	Input	Real	100,00
Cast mass	Input	Integer	100,00
Weibull distribution shape parameter	Output	Real	100,00

Fig. 6 Expert system parameters

Name	Mark	Point A	Point B	Point C	Point D
☑ Small LRRF	MM	0	0	0,3	0,4
☑ Medium LRRF	MS	0,3	0,4	0,6	0,7
☑ Big LRRF	MV	0,6	0,7	1	1

Fig. 7 Fuzzy sets quantity low risk relative frequency

5.4 Practical exhibit of the system work

Input query (Fig. 8):
Overheating above the liquid temp.: 50
Casting speed: 47,08
Aluminium content : 0,025

Name	Type	Value
Overheating above the liquid temperature	Integer	50
Casting speed	Real	47,08
Aluminium content	Real	0,025

Fig. 8 Parameters practical exhibit

Resultant risk: medium risk (Fig. 9).
Subsequently there are calculated the cumulative relative frequencies for a given instant of time that serve as the inputs into the expert system for Weibull distribution shape parameter determination.

Input query:
Relative frequency of a small risk: 0,6280
Relative frequency of a medium risk : 0,3387
Relative frequency of a peak risk : 0,0076
Cast mass: 5960

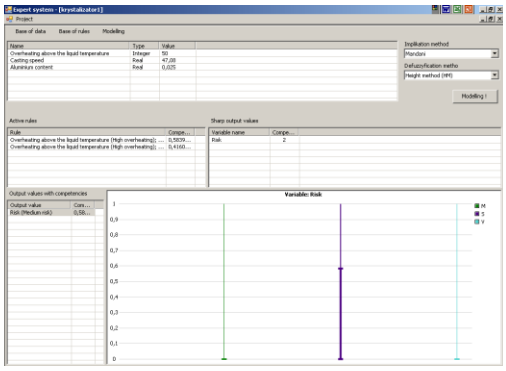


Fig. 9 Data base screen practical exhibit

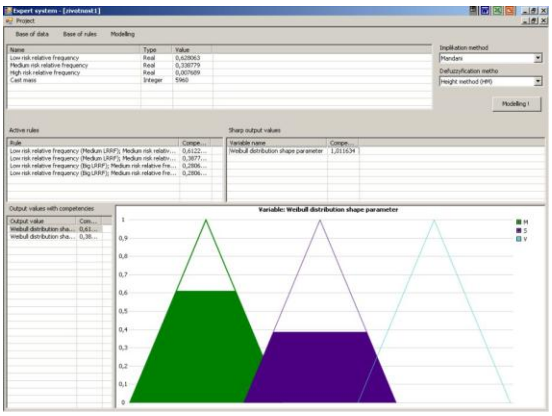


Fig. 10 Data base screen practical exhibit

Shape parameter output value : 1,011634 (Fig. 10)

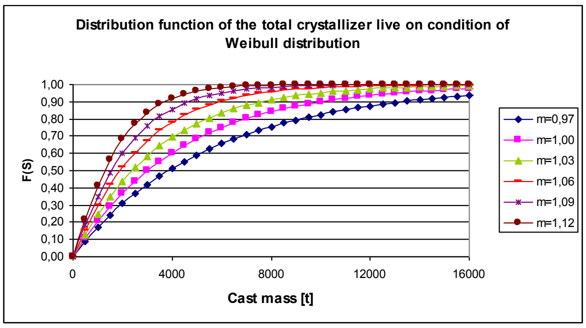


Fig. 11 Distribution function of crystallizer total life

Calculation of the spot estimation of the cast mass up to the crystallizer technical life expiration: 11658 t. Calculation of the spot estimation residual life: 5698 t. The real value of total cast mass on the particular crystallizer was 11790 tons.

6. Conclusion

The inception of an equipment limiting state is effected by several impacts and processes that work and run directly on the equipment and its individual parts of the during its operation. These effects result in changing the characteristics of some functional faces of the equipment and its parts and they become the primary technical signs of the limiting state inception influencing both the process effectiveness and the equipment service life. The suggested algorithm consists in evaluation of the crystallizer wear exposure at individual process stages in casting the individual heats at the moments of measuring the technological parameters in casting process.

The actual results show that in these cases it is necessary to apply a new modern approach based not only on the exploitation of objective qualitative knowledge, but also on human experience it means the subjective and heuristic knowledge. This will result in methods that use for construction of effective model structures the same principles as those used by a human expert. This way of approaching the investigation of complicated systems leads to the employment of the knowledge based systems.

The results achieved in the designed system for solution to the crystallizer residual technical life show, that the existing problem can be resolved by exploitation of the knowledge system.

References

[1] VROŽINA M. *Exploitation of knowledge systems in metallurgical equipments maintenance control by engaging the continuous diagnostics in solution* .Ostrava: VŠB-TU Ostrava, 2004.

[2] DAVID, J., HEGER, M., VROŽINA, M., VÁLEK, L. Visualisation of data fields. *Archives Of Metallurgy and Materials*. 2010, Volume: 55, Issue: 3 , stránky 795-801.ISSN 1733-3490

[3] POČTA J. *Machines maintenance and repairs technology*. Prague ČZU Prague H&H,1995.

[4] *Continuous pigs casting*: regulation for assembly and maintenance; the plate type crystallizers. CLESIM, 1987 firm materials.

[5] ZADEH L. A. *Fuzzy sets and their applications to cognitive and decision processes.* New York: Academic Press, 1975.

[6] TOMIS, L., DAVID, J. Využití cepstrální informace pro diagnostiku technologie plynulého odlévání oceli. *Hutnické listy*, 2008, č 2., roč. LXI, s.76-82. ISSN 0018-8069

[7] LENORT, R.; BESTA, P. Logistics of End of Life Electronics Equipment Disassembly. *Acta Montanistica Slovaca*, vol. 14 (2009), no. 3, pp. 268-274. ISSN 1335-1788.

[8] PENKALA P. Využití umělé inteligence při řízení systémů. Graduation theses VŠB – TU Ostrava, Ostrava, 2005.

[9] KREJCAR, O., FRISCHER, R. Non Destructive Defect Detection by Spectral Density Analysis. *SENSORS*. vol. 11, Iss. 3, pp. 2334-2346, 2011. DOI 10.3390/s110302334. ISSN: 1424-8220.

[10] LENORT, R.; SAMOLEJOVÁ, A. Analysis and Identification of Floating Capacity Bottlenecks in Metallurgical Production. *Metalurgija*, January-March 2007, vol. 46, no. 1, s. 61-66. ISSN 0543-5846.

[11] JANČÍKOVÁ, Z., ROUBÍČEK, V., JUCHELKOVÁ, D. Application of Artificial Intelligence Methods for Prediction of Steel Mechanical Properties. *Metalurgija*, 47 (2008) 2, s. 133-137, ISSN 0543-5846

[12] ŠVEC, P., JANČÍKOVÁ, Z., MELECKÝ, J., KOŠTIAL, P. Implementation of Neural Networks for Prediction of Chemical Composition of Refining Slag. In *International Conference on Metallurgy and Materials*, Hradec nad Moravicí, 2010, s. 155-159,ISBN 978-80-87294-17-8