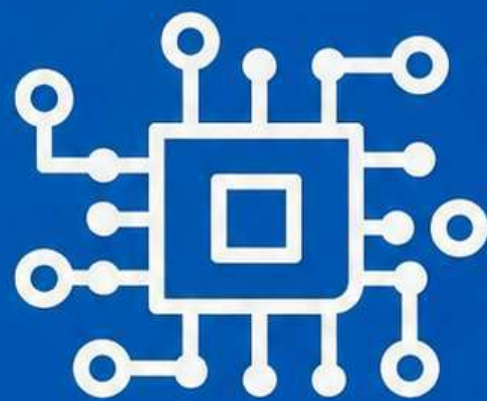




TECH SCIENCE

ISSN 3030-3702

**TEXNIKA FANLARINING
DOLZARB MASALALARI**

**TOPICAL ISSUES OF TECHNICAL
SCIENCES**



**№ 4-maxsus
son (4) 2026**

BOSH MUHARRIR:

ABBAZOV ILHOM ZAPIROVICH

TAHRIR HAY'ATI:

Usmankulov Alisher Kadirkulovich — Texnika fanlari doktori, professor, Jizzax, O'zbekiston;

Fayziyev Xomitxon – texnika fanlari doktori, professor, Toshkent, O'zbekiston;

Rashidov Yusuf Karimovich – texnika fanlari doktori, professor, Toshkent, O'zbekiston;

Adizov Bobirjon Zamirovich – Texnika fanlari doktori, professor, Toshkent, O'zbekiston;

Abdunazarov Jamshid Nurmuxamatovich — Texnika fanlari doktori, dotsent, Jizzax, O'zbekiston;

Eshonkulov Ravshan Abdurazakovich — Texnika fanlari doktori, dotsent, Qashqadaryo, O'zbekiston;

Umarov Shavkat Isomiddinovich – Texnika fanlari doktori, professor, Jizzax, O'zbekiston;

Bozorov G'ayrat Rashidovich – Texnika fanlari doktori, Buxoro, O'zbekiston;

Maxmudov Muxtor Jamolovich – Texnika fanlari doktori, Buxoro, O'zbekiston;

Asatov Nurmuxammad Abdunazarovich – Texnika fanlari nomzodi, professor, Jizzax, O'zbekiston;

Mamayev G'ulom Ibroximovich – Texnika fanlari bo'yicha falsafa doktori (PhD), Jizzax, O'zbekiston;

Ochilov Abduraxim Abdurasulovich – Texnika fanlari bo'yicha falsafa doktori (PhD), Buxoro, O'zbekiston.

OAK Ro'yxati

Mazkur jurnal O'zbekiston Respublikasi Oliy ta'lim, fan va innovatsiyalar vazirligi huzuridagi Oliy attestatsiya komissiyasi Rayosatining 2025-yil 8-maydagi 370-son qarori bilan texnika fanlari bo'yicha ilmiy darajalar yuzasidan dissertatsiyalar asosiy natijalarini chop etish tavsiya etilgan ilmiy nashrlar ro'yxatiga kiritilgan.

Muassislar: "SCIENCEPROBLEMS TEAM" mas'uliyati cheklangan jamiyati;
Jizzax politexnika instituti.

TECHSCIENCE.UZ- TEXNIKA**FANLARINING DOLZARB****MASALALARI** elektron jurnali

15.09.2023-yilda 130343-sonli

guvohnoma bilan davlat ro'yxatidan o'tkazilgan.

TAHRIRIYAT MANZILI:

Toshkent shahri, Yakkasaroy tumani, Kichik Beshyog'och ko'chasi, 70/10-uy.

Elektron manzil:

scienceproblems.uz@gmail.com

Barcha huquqlar himoyalangan.

© Scienceproblems team, 2026-yil

© Mualliflar jamoasi, 2026-yil

MUNDARIJA

<i>Mamirov Uktam, Khudoyberdiyev Asror</i> FUZZY-LOGIC-BASED ASSESSMENT OF THE DURABILITY CRITERION OF A CONTINUOUS CASTING MACHINE	4-12
<i>Shanning Fu, Ya Han, Bekmurotov Dilshod</i> CONTROLLED EVALUATION OF STATE-AWARE AND VERIFIABLE RAG FOR ENGLISH-LANGUAGE TUTORING: RETRIEVAL RELIABILITY, GROUNDING, AND VERIFICATION	13-26
<i>Fayzullayev Xayriddin</i> MUHANDISLIK GRAFIKASI FANINI O'RGANISHDA "TEKISLIK LARNING KESISHISHI" MAVZUSINI O'QITISH USULI	27-32
<i>Muinov Ulug'bek, Usmonov Botir</i> KICHIK QUUVATLI SHAMOL ENERGETIK TIZIMIDA PI-ROSTLAGICH ASOSIDA KUCHLANISHNI BOSHQARISH	33-44
<i>Sayitov Shavkatjon, Sarimsakov Olimjon</i> PAXTA XOMASHYOSINI QURITISHNING KO'P PARAMETRLI AVTOMATLASHTIRILGAN MONITOTING TIZIMINI ISHLAB CHIQISH	45-50
<i>Haitov Bozar</i> BISMUT VOLFRAMAT (Bi_2WO_6 , BiWO_4) NI SINTEZ QILISH USULLARI: ZAMONAVIY YONDASHUVLAR TAHLILI	51-58
<i>Ishnazarov Oybek, Hoshimov Ural</i> KOMPRESSOR USKUNASINI AVTOMATLASHTIRILGAN ISHLASH REJIMIDAGI DINAMIK JARAYONLARNING TAHLILI	59-67
<i>Shavazov Abdulatif, Turaxanov Sherzod, Ilekeroval Indira</i> BOSHQARILUVCHI ELEKTR YURITMALAR ISH REJIMLARINI OPTIMALLASHTIRISH USULLARINI TAKOMILLASHTIRISH.....	68-75
<i>Nurlibayeva Zarina</i> TIKUV MASHINASI IGNA IPINI TARANGLAGICHINING QAYISHQOQ ELEMENTLI KONSTRUKTIV PARAMETRLARINI TADBIQ ETISH	76-83
<i>Bazarov Baxtiyor, Odilov Odiljon, Bo'tayev Azizjon</i> SINTETIK GAZ YONILG'ISIDAN FOYDALANIB CHEVROLET COBALT VA CHEVROLET TRACKER YENGIL AVTOMOBILLARINING EKSPLOATATSION KO'RSATKICHLARINI OSHIRISH: MATLAB/SIMULINK ASOSIDAGI MODELLASHTIRISH TADQIQOTI	84-90
<i>Karimxodjayev Nazirjon, Ismatov Biloldin</i> ELEKTROMOBIL BATAREYALARINI ZARYADLASH JARAYONIDA YASHIRIN KRITIK HOLATLARNI AMALIY DIAGNOSTIKA QILISH METODIKASI	91-99
<i>Musurmonov Ulug'bek</i> POLIMER MODIFIKATSIYALANGAN BITUM ASOSIDA ASFALT-BETON QORISHMASINING FIZIK-MEXANIK XUSUSIYATLARINI TADQIQ ETISH.....	100-107

FUZZY-LOGIC-BASED ASSESSMENT OF THE DURABILITY CRITERION OF A CONTINUOUS CASTING MACHINE

Mamirov Oktam Farkhodovich

Doctor of Technical Sciences,

Professor at Tashkent State Technical University named after Islam Karimov

ORCID: 0000-0002-5596-2819

Khudoyberdiev Asror Fakhridin ugli

Master's student at Tashkent State Technical University named after Islam Karimov

Email: asrorspace@gmail.com

Tel: +998997563356

Annotation. The paper presents a fuzzy-logic model for assessing the durability criterion of roller sections in the secondary cooling zone of a continuous casting machine. It is a chain of three fuzzy controllers with casting speed, water flow, casting temperature and number of heats as inputs. Simulation results support condition-based maintenance planning.

Key words: continuous casting machine, roller section, fuzzy logic, membership function, durability criterion, technical condition, maintenance planning, neuro-fuzzy network.

UZLUKSIZ QUYISH MASHINASI UZOQ XIZMAT QILISH MEZONINI NORAVSHAN MANTIQ ASOSIDA BAHOLASH

Mamirov O'ktam Farxodovich

Texnika fanlari doktori, Islom Karimov nomidagi

Toshkent davlat texnika universiteti professori

Xudoyberdiyev Asror Faxriddin o'g'li

Islom Karimov nomidagi Toshkent davlat texnika universiteti

magistranti

Annotatsiya. Maqolada uzluksiz quyish mashinasi ikkilamchi sovitish zonasi rolikli seksiyalarining uzoq xizmat qilish mezonini noravshan mantiq asosida baholash modeli ko'rib chiqilgan. Model uchta ketma-ket noravshan kontrollerdan iborat bo'lib, kirish sifatida quyish tezligi, suv sarfi, quyish harorati va eritishlar soni olinadi. Modellash natijalari ta'mirlash ishlarini texnik holatga ko'ra rejalashtirish imkonini beradi.

Kalit so'zlar: uzluksiz quyish mashinasi, rolikli seksiya, noravshan mantiq, tegishlilik funksiyasi, uzoq xizmat qilish mezon, texnik holat, ta'mirlashni rejalashtirish, neyro-noravshan tarmoq.

DOI: <https://doi.org/10.47390/ts-v4is/4y2026N01>

Introduction.

Continuous casting is today the dominant route for converting liquid steel into semi-finished products: more than 95 % of the world's crude steel passes through a continuous casting machine (CCM). The machine operates around the clock in contact with metal at 1500–

1600 °C, under cyclic thermal and mechanical loads, in a steam-and-scale atmosphere. Under such conditions the roller sections of the secondary cooling zone (SCZ), which support and guide the solidifying strand, wear out faster than any other unit of the caster. According to the operational statistics analysed in [11; p. 40–48], roller sections account for the largest share of unplanned stoppages of a slab caster, while the mould accounts for the most severe consequences of a failure.

The traditional way of keeping such equipment in working order is the scheduled preventive maintenance (SPM) system: every section is replaced after a fixed number of heats or after a fixed calendar interval, regardless of its actual state. This approach has two well-known drawbacks. Sections that operated under mild conditions are removed while they still have a considerable residual life, which increases the cost of spare parts and the number of stoppages; sections that operated under severe conditions may fail before the scheduled replacement date, causing unplanned downtime, strand defects and, in the worst case, a breakout.

A transition to condition-based maintenance requires a quantitative estimate of the technical state of every section at any moment of time. The difficulty is that the wear of a roller is not measured directly during operation. It has to be inferred from indirect process parameters (casting speed, cooling-water flow, casting temperature, number of heats) that are recorded by the automated control system (ACS) of the caster with noise, gaps and drift, and from expert judgements formulated in words such as “high speed”, “insufficient cooling”. Classical reliability models based on probability theory need complete and statistically homogeneous failure data, which are rarely available in a real steel shop [11; p. 5–6].

Fuzzy logic, introduced by L. Zadeh [9], is a natural mathematical tool for this class of problems, because it allows linguistic knowledge of technologists to be combined with imprecise numerical measurements in a single computational model. The aim of the present paper is to describe a compact fuzzy model for assessing the durability criterion of SCZ roller sections, to demonstrate its behaviour by simulation, and to show how its output can be used for maintenance planning. The paper is written at the level of a master’s study and is based on the results obtained for a slab caster of a converter shop [11], reformulated and reproduced in an independent computational experiment.

Literature review and methodology.

The mathematical modelling of continuous casting has a long history; a comprehensive review of thermal, mechanical and fluid-flow models of the process is given by B. Thomas [7]. These models describe the strand, but not the ageing of the machine itself. The state of the equipment has traditionally been studied within reliability theory (failure trees, reliability block diagrams, distributions of time to failure). Such methods, as noted in [11; p. 12–32], give an a priori estimate for a population of identical units, but cannot “follow” an individual unit whose loading history is known only approximately.

Fuzzy inference systems have been applied to continuous casting mainly for on-line control tasks. A. Bhattacharya and co-authors [2] developed a fuzzy system that recognises fault-signature patterns in mould thermocouple data and regulates the casting speed to prevent breakouts. J. David and co-authors [3] combined dependability theory with artificial neural networks to model the technical lifetime of CCM moulds and proposed a linguistic model for the identification of casting defects. The most complete application of fuzzy logic to the assessment of CCM equipment state is the work of O. Solovyeva [11], in which a hierarchical

neuro-fuzzy model of the whole caster was built and validated on production data of a converter shop for 2002–2007. In the broader field of predictive maintenance, data-driven estimation of the remaining useful life (RUL) of equipment by neural networks [5] and by probabilistic prognostic models coupled with decision-making agents [8] is currently the mainstream direction; fuzzy and neuro-fuzzy models remain attractive because their rules are transparent and interpretable by plant engineers.

The methodology adopted in this paper consists of four steps: (1) selection of the influencing parameters and definition of linguistic variables; (2) construction of a hierarchical fuzzy model from three cascaded fuzzy controllers; (3) implementation of the model and computation of its input-output surfaces; (4) analysis of the dependence of the durability criterion on the operating regime and formulation of recommendations for maintenance planning. The inference mechanism is of the Sugeno type of zero order [4; p. 667–668] with Gaussian membership functions and weighted-average defuzzification; this choice keeps the model smooth and easy to tune with neuro-fuzzy learning [4], [10]. All computations were carried out in Python with the NumPy library; the same model can be built without changes in the MATLAB Fuzzy Logic Toolbox.

Discussion.

Structure of the model. The durability criterion I (%) of a roller section is understood as the share of its residual resource: $I = 100$ % corresponds to a new section, $I = 0$ % to the limiting state at which further operation is not allowed. The criterion is computed by a chain of three fuzzy controllers (Fig. 1). The first controller estimates the criterion of damage accumulation D (%) from two parameters that determine the thermal regime of the roller: the casting speed S (m/min) and the flow of cooling water Q (m³/h). A low speed prolongs the contact of each roller with the hot strand, and a small water flow makes the roller surface overheat; both factors accelerate the formation of thermal fatigue cracks. The second controller corrects the accumulated damage for the casting temperature T (°C) and produces the corrected criterion $D2$ (%). The third controller combines $D2$ with the number of heats P cast since the last replacement and yields the durability criterion I .

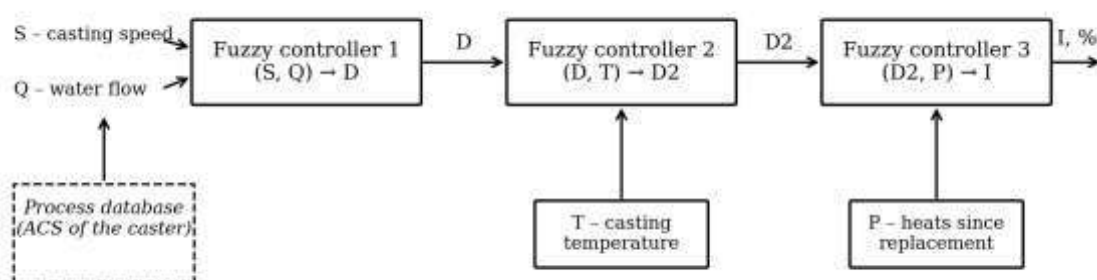


Fig. 1 – Structure of the fuzzy model for assessing the durability criterion of an SCZ roller section.

The cascade structure has an important practical advantage: each controller has only two inputs, so its rule base is a small matrix that can be filled in and checked by an experienced technologist. A single controller with four inputs and three terms per input would require 81 rules, which is difficult to formulate consistently.

Linguistic variables. Each input and intermediate variable is described by three terms — “low” (L), “medium” (M), “high” (H); the output of every controller is described by five terms — “very low” (VL), “low” (L), “medium” (M), “high” (H) and “very high” (VH). The universes of the

variables (Table 1) correspond to the operating ranges of a slab caster of a converter shop [11; p. 71].

Table 1.

Linguistic variables of the model

Symbol	Variable	Universe	Terms
S	Casting speed	0.6–1.3 m/min	L, M, H
Q	Cooling-water flow in the SCZ	8–20 m ³ /h	L, M, H
T	Casting temperature	1530–1590 °C	L, M, H
P	Heats since section replacement	0–1000 heats	L, M, H
D	Damage accumulation criterion	0–100 %	VL, L, M, H, VH
D2	Corrected damage criterion	0–100 %	VL, L, M, H, VH
I	Durability criterion	0–100 %	VL, L, M, H, VH

Membership functions. Statistical analysis of the casting parameters in [11; p. 156–160] showed that their distributions are close to normal, so a Gaussian form of the membership function was adopted:

$$\mu(x) = \exp(-(x - b)^2 / (2h^2)), \quad (1)$$

where b is the coordinate of the maximum of the function and h is the concentration coefficient (width). In the initial model the three terms of each input are placed uniformly over the universe: the centres b coincide with its lower bound, middle and upper bound, and the width h is chosen so that adjacent functions intersect at the level $\mu = 0.5$ (Table 2, Fig. 2). Such an initial arrangement is the usual starting point for subsequent fine tuning of the parameters b and h by the ANFIS learning procedure [4] on production data; in [11; p. 90–92] this tuning reduced the modelling error to 3–6 %.

Table 2.

Parameters of the Gaussian membership functions of the input variables

Variable	b (L)	b (M)	b (H)	h
S, m/min	0.60	0.95	1.30	0.149
Q, m ³ /h	8.0	14.0	20.0	2.55
T, °C	1530	1560	1590	12.7
P, heats	0	500	1000	212
D, D2, %	0	50	100	21.2

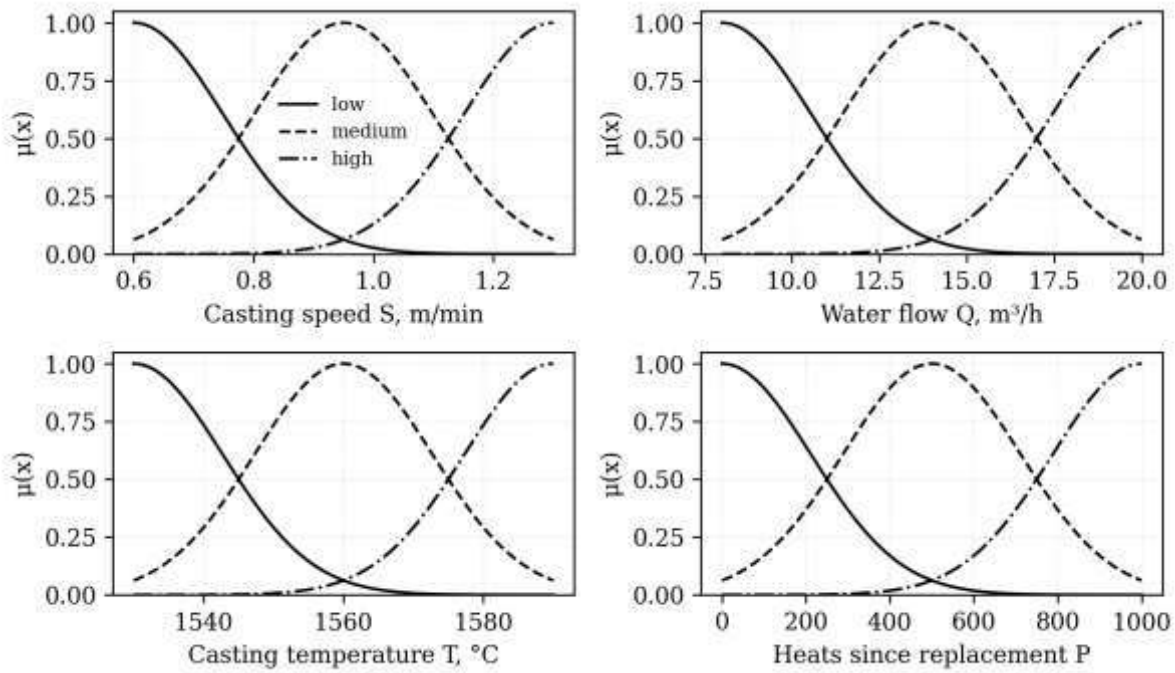


Fig. 2 – Membership functions of the input linguistic variables

Rule bases. The rules of each controller have the form “IF x_1 is A AND x_2 is B THEN y is C”. The antecedents are combined by the algebraic product, which preserves the continuity of the model with respect to the membership-function parameters [11; p. 65]. The three rule bases contain nine rules each and are given in Table 3 in matrix form; the rows correspond to the terms of the first input and the columns to the terms of the second input.

Table 3.

Knowledge matrices of the three fuzzy controllers

Controller 1: $D = f(S, Q)$	$Q = L$	$Q = M$	$Q = H$	Controller 2: $D2 = f(D, T)$	$T = L$	$T = M$	$T = H$	Controller 3: $I = f(D2, P)$	$P = L$	$P = M$	$P = H$
$S = L$	VH	H	M	$D = L$	M	L	VL	$D2 = L$	VH	H	M
$S = M$	H	M	L	$D = M$	H	M	L	$D2 = M$	H	M	L
$S = H$	M	L	VL	$D = H$	VH	H	M	$D2 = H$	M	L	VL

The matrices encode the following technological reasoning. Damage accumulates fastest when the speed is low and the water flow is small (rule “ $S = L$ and $Q = L \rightarrow D = VH$ ”), and slowest in the opposite corner of the matrix. A higher casting temperature aggravates the thermal loading of the rollers, so for the same D the corrected criterion $D2$ grows with T . Finally, the residual resource I is high only when little damage has accumulated and the section is young; a section with high $D2$ that has already cast many heats is close to its limiting state.

Inference and defuzzification. For crisp inputs x_1, x_2 the firing strength of the rule (i, j) is $w_{ij} = \mu_i(x_1) \cdot \mu_j(x_2)$. The output of the controller is the weighted average of the singleton values c_{ij} assigned to the output terms ($VL = 0, L = 25, M = 50, H = 75, VH = 100\%$):

$$y = \sum w_{ij} \cdot c_{ij} / \sum w_{ij}. \quad (2)$$

Formula (2) is the zero-order Sugeno inference; it is computationally cheap and can be executed for every section of the caster in real time by the application server of the ACS. Fig. 3 shows the input-output surfaces of the three controllers computed by (1), (2). All surfaces are smooth and monotonic, which confirms that the rule bases are complete and free of contradictions.

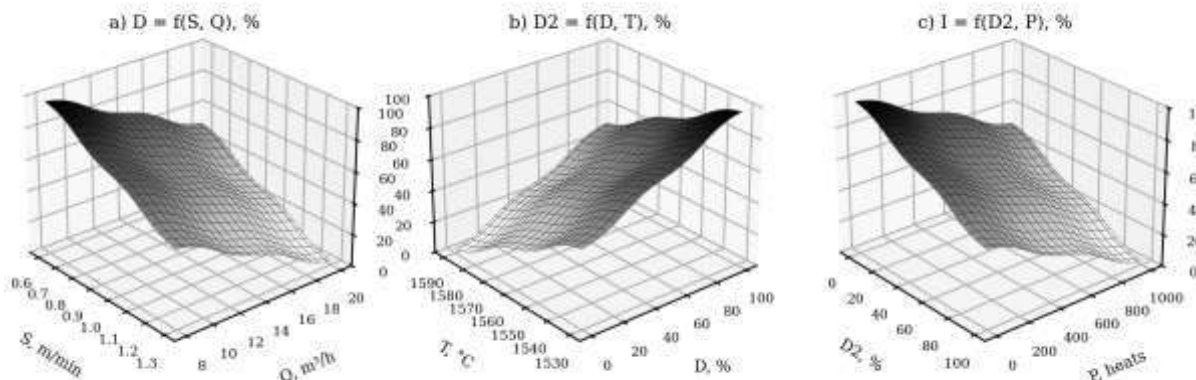


Fig. 3 – Input-output surfaces of the fuzzy controllers: a – damage accumulation; b – temperature correction; c – durability criterion.

Assessment algorithm. In the information system of the caster the model is executed as the following sequence of steps for every roller section after every heat: (1) the values of S , Q and T are read from the process database of the ACS and averaged over the heat; (2) the counter P of heats since the last replacement is updated from the maintenance log; (3) missing or clearly erroneous readings (sensor drift, communication gaps) are replaced by the values of the corresponding cluster centre obtained by fuzzy c-means clustering of the historical data [1]; (4) the three controllers are executed in turn by formulas (1), (2); (5) the value of I is written to the database and compared with two thresholds — a warning level ($I \leq 40$ %) and a replacement level ($I \leq 30$ %); (6) the result is displayed on the operator's workstation as a state diagram of all sections of the strand. Step (3) is important in practice: according to [11; p. 116–117], the production database of a converter shop contained gaps in the values of a number of variables, which was one of the reasons for choosing a fuzzy rather than a regression model.

Results.

The model was used to calculate the durability criterion for several typical operating points of a slab caster (Table 4). The points were chosen to cover a mild regime (high speed, intensive cooling, high temperature), the nominal regime and a severe regime (low speed, weak cooling, low temperature).

Table 4.

Results of the assessment for typical operating points

No.	S, m/min	Q, m ³ /h	T, °C	P, heats	D, %	D2, %	I, %	Recommendation
1	1.15	17	1590	150	22.7	12.4	88.8	continue operation
2	1.00	14	1560	300	47.6	49.3	59.2	continue operation
3	1.00	14	1560	600	47.6	49.3	46.7	inspection at next stop
4	0.95	13.5	1555	850	51.3	53.2	30.2	plan replacement
5	0.85	11	1540	450	68.0	75.5	38.8	inspection at next stop
6	0.85	11	1540	700	68.0	75.5	28.2	replace

The results are consistent with plant experience: in the mild regime a section that has cast 150 heats retains almost 90 % of its resource, whereas in the severe regime the same criterion falls below 30 % after 700 heats. It is instructive to compare points 3 and 5: the section in point 5 has cast fewer heats (450 against 600), yet its durability criterion is lower, because the severe thermal regime has accumulated more damage. A purely calendar-based or heat-count-based schedule would treat these two sections in the wrong order.

Fig. 4 shows the dependence of the durability criterion on the number of heats for the three regimes. A replacement threshold $I = 30\%$ was adopted, which corresponds to the level at which, according to [11; p. 121–124], the growth rate of the wear criterion begins to exceed the growth rate of the number of heats. Under the nominal regime the threshold is reached after approximately 880 heats, which agrees with the standard replacement interval of 750–1000 heats used in the technological instructions of the shop [11; p. 122]. Under the severe regime the threshold is reached after approximately 670 heats, i.e. the section should be replaced about 25 % earlier than the schedule prescribes; under the mild regime the criterion remains above 45 % even after 1000 heats, so the service life of such a section can be safely extended.

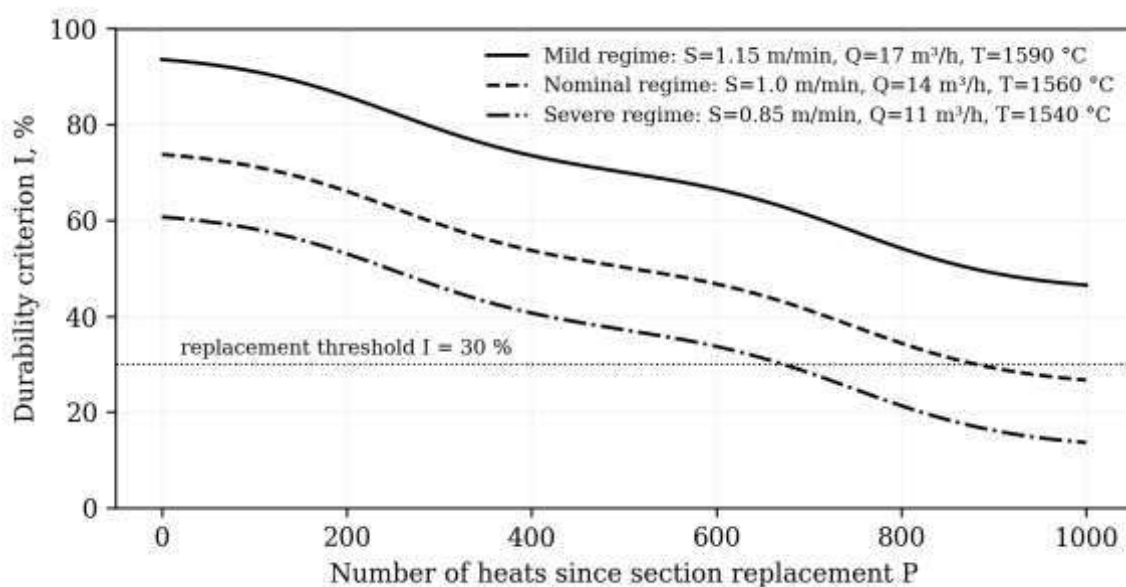


Fig. 4 – Dependence of the durability criterion I on the number of heats P for three operating regimes.

Table 5 summarises the comparison of the schedule-based and the condition-based replacement for the three regimes. For the mild regime the model indicates that a section removed after 1000 heats still has almost half of its resource; for the severe regime the schedule-based replacement comes about 330 heats too late, i.e. the section operates for roughly one third of its scheduled life in a zone of elevated failure risk.

Table 5.

Comparison of schedule-based and condition-based replacement

Operating regime	Heats to threshold $I = 30\%$ (model)	Scheduled replacement, heats	Deviation, heats	Consequence of the fixed schedule
Mild	> 1000 ($I = 46.7\%$ at 1000 heats)	1000	> 0	resource wasted, extra stoppage
Nominal	≈ 880	1000	-120	small risk of failure near the end
Severe	≈ 670	1000	-330	high risk of failure and breakout

The adequacy of a fuzzy model of this type was confirmed in [11; p. 116–128] on the data of a slab caster of a converter shop: for the roller sections of the SCZ the coefficient of correlation between the modelled durability criterion and the actual number of heats to replacement was $r = 0.98$ (coefficient of determination $R^2 = 0.966$), and for the mould $r = 0.97$; the regression equations were statistically significant according to Fisher's F-test. The model presented here reproduces the qualitative behaviour of the validated model with untuned membership functions; after tuning by ANFIS on the data of a particular caster the same accuracy can be expected.

From the point of view of maintenance planning the output of the model can be used in three ways. First, the value of I for every section is displayed on the operator's workstation as a state diagram, so that engineers see which sections are approaching the threshold. Second, sections are ranked by I , and the repair programme for the next stop is composed from the sections with the lowest values, rather than from all sections whose calendar interval has expired. Third, the number of heats at which I is expected to cross the threshold is extrapolated from the current trend, which gives a forecast of the replacement date. According to the estimates in [11; p. 128–134], such condition-based planning would have prevented about 20 % of the stoppages of the caster during the year analysed and reduces the maintenance budget by up to 20 % while preserving the required level of reliability.

Conclusion.

1. The durability criterion of roller sections of the secondary cooling zone of a continuous casting machine can be assessed by a compact hierarchical fuzzy model consisting of three cascaded controllers with two inputs each. The cascade structure reduces the number of rules to 27, so the knowledge base can be formulated and verified by plant technologists.

2. Gaussian membership functions uniformly arranged over the operating ranges of casting speed, water flow, casting temperature and number of heats give smooth and monotonic input-output surfaces; the model is therefore suitable as an initial structure for neuro-fuzzy tuning on production data.

3. Simulation showed that the durability criterion depends strongly on the operating regime: under the severe regime the replacement threshold is reached about 25 % earlier than under the nominal regime, while under the mild regime the service life can be extended beyond the standard 1000 heats. A schedule based only on the number of heats therefore either wastes resource or accepts an increased risk of failure.

4. The output of the model can be integrated into the existing automated control system of the caster and used for condition-based ranking of sections, composition of repair programmes and forecasting of replacement dates. Further work will be devoted to tuning the membership functions on the data of a domestic metallurgical plant and to extending the model to the mould and the drive roller sections.

Adabiyotlar/Литература/References:

1. Bezdek J.C. Pattern Recognition with Fuzzy Objective Function Algorithms. – New York: Plenum Press, 1981. – 256 p.
2. Bhattacharya A.K., Srinivas P.S., Chithra K., Jatla S.V., Das J. Recognition of Fault Signature Patterns Using Fuzzy Logic for Prevention of Breakdowns in Steel Continuous Casting Process // Pattern Recognition and Machine Intelligence. Lecture Notes in Computer Science, Vol. 3776. – Berlin: Springer, 2005. – P. 318–324.
3. David J., Švec P., Garzinová R., Kluska-Nawarecka S., Wilk-Kołodziejczyk D., Regulski K. Heuristic modeling of casting processes under the conditions uncertainty // Archives of Civil and Mechanical Engineering. – 2016. – Vol. 16, No. 2. – P. 179–185.
4. Jang J.-S.R. ANFIS: Adaptive-Network-Based Fuzzy Inference System // IEEE Transactions on Systems, Man, and Cybernetics. – 1993. – Vol. 23, No. 3. – P. 665–685.
5. Kang Z., Catal C., Tekinerdogan B. Remaining Useful Life (RUL) Prediction of Equipment in Production Lines Using Artificial Neural Networks // Sensors. – 2021. – Vol. 21, No. 3. – Art. 932.
6. Mamdani E.H., Assilian S. An experiment in linguistic synthesis with a fuzzy logic controller // International Journal of Man-Machine Studies. – 1975. – Vol. 7, No. 1. – P. 1–13.
7. Thomas B.G. Review on Modeling and Simulation of Continuous Casting // Steel Research International. – 2018. – Vol. 89, No. 1. – Art. 1700312.
8. Xu Z., Zhang Q. Predictive maintenance optimization for industrial equipment via reliable prognosis and risk-aware reinforcement learning // Complex & Intelligent Systems. – 2025. – Vol. 11. – DOI: 10.1007/s40747-025-02127-w.
9. Zadeh L.A. Fuzzy sets // Information and Control. – 1965. – Vol. 8, No. 3. – P. 338–353.
10. Рутковская Д., Пилиньский М., Рутковский Л. Нейронные сети, генетические алгоритмы и нечеткие системы. – М.: Горячая линия – Телеком, 2006. – 452 с.
11. Соловьева О.И. Метод и алгоритмы оценки состояния оборудования непрерывной разливки стали на основе аппарата нечеткой логики: дис. ... канд. техн. наук: 05.13.01. – Череповец: ЧГУ, 2014. – 179 с.

TECHSCIENCE.UZ

**TEXNIKA FANLARINING DOLZARB
MASALALARI**

№ S/4 (4)-2026

TOPICAL ISSUES OF TECHNICAL SCIENCES

**TECHSCIENCE.UZ- TEXNIKA
FANLARINING DOLZARB MASALALARI**
elektron jurnali 15.09.2023-yilda 130346-
sonli guvohnoma bilan davlat ro'yxatidan
o'tkazilgan.

Muassislar: "SCIENCEPROBLEMS TEAM"
mas'uliyati cheklangan jamiyati;
Jizzax politexnika insituti.

TAHRIRIYAT MANZILI:

Toshkent shahri, Yakkasaroy tumani, Kichik
Beshyog'och ko'chasi, 70/10-uy.

Elektron manzil:

scienceproblems.uz@gmail.com