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DETERMINATION OF THE KEY OPERATIONAL FEATURES IN THE STEEL CONTINUOUS CASTING PROCESSES

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The processes of continuous steel casting should be realized in a way ensuring obtaining the designed quality properties of the cast. The basis of the balanced development, however, cause that the tendencies toward the continuous casting improvement are directed toward the minimizing its negative influence on the environment. The subject of the analysis is, considering the risk assessment, identification of the key-operational-features in the continuous casting process. The proposed methodology is of the utilitarian characteristics and can find the application in each organization which due to the operational monitoring wants to eliminate the defects and the environmental impacts within the realized processes.

Key words: steel, continuous casting, defects, environmental aspects, operational parameters

INTRODUCTION

The examination of the cast during the control process usually concerns the following: weight, size, chemical composition, durability features and structure. The cast should be free from any of: shape defect, surface defect, breaks in continuity and internal defect [1]. However, one should bear in mind that the control process – taking advantage of both: damaging and non-damaging methods of examination – can only confirm or exclude the defect occurrence, and is not the preventive tool [2].

During the casting process the technological parameters define the structure features, which in turn have direct influence on the mechanical properties of the cast [2-4].

Such a dependence has pointed the conditions of the process' control. The development of the technology of continuous casting pinpoints not only the necessity of meeting the technological requirements set to the final product. The modern solutions consider also the strong influence exerted on the environment. The need of minimizing the negative environmental influence of technology leads to either resigning from application or forcing the organization to apply the tools of preventive properties [5].

As the system tool ensuring the repetitiveness of the preventive actions taken against the defects and the environmental impacts within the technological process, one should definitely consider the new standards: ISO 9001:2015 and ISO 14001:2015, and especially these ones which directly concern the realization of the technological process – requirements within the operational control. One should also strongly stress that the standards in question impose on the organization the obligation of the operational control, however, not pointing any methods or tools which should be applied in the range of the operational control [6, 7].

The operational control can be interpreted, surely, as the condition of the controlled risk within the process. Identification of the key-operational parameters of the process, defining the way of their control as well as the actions in case of emergency can constitute the solid base of the stable realization [8, 9].

Taking the above presented as the study's aim, one has set the development of the identification methodology for the key-operational features of the technological process and applying it within the continuous steel casting.

METHODOLOGY

The developed methodology enables indication within the technological process of these operational features which represents the highest level of influencing the fulfillment of the requirements set by both: clients and the interested parties. It reflects the originality of the study. Due to the control process over the realized process, for ensuring the compatibility with the specific requirements, the key-operational features must undergo the operational monitoring. Within the integrated scope, the operational features are represented not only by the defects of the quality parameters but also the environmental aspects and impacts.

Identification of the key-operational features (Figure 1) covers: description of the technological features

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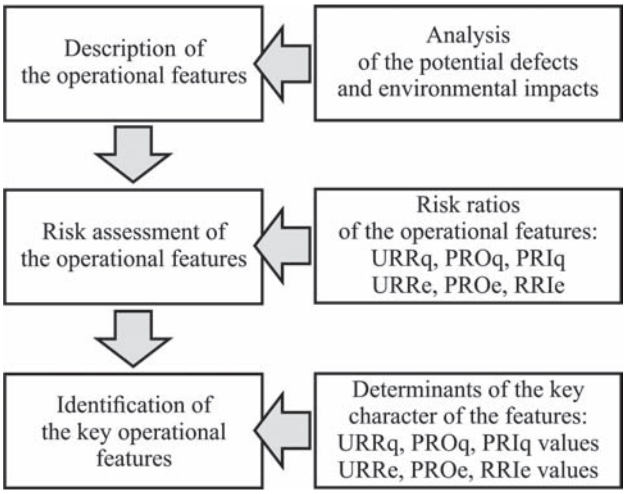

Figure 1 Scheme of the methodology of key-operational features identification.

– potential defects and the environmental impacts, definition of the measurements of the risk assessment of the technological features determining the key character, definition of the determinants' value pointing their key character as well as pointing out the operational features of the key character.

The ratio of the risk assessment of the particular operational features are the following:

- Quality and environmental unit risk ratios (URRq, URRe) describing the risk connected with the occurrence of the single defect and the environmental impact,
- Priority ratios of the occurrence and the importance of defects and environmental aspects (PROq, PROe, PRIq, PRIe).

The risk connected with the defect occurrence has been described as the dependence between the frequency of the defect occurrence and its importance and expressed as:

$$URRq = PROq \cdot PRIq \qquad (1)$$

where the following means:

URRq – Quality unit risk ratio,

PROq – Priority ratio of defect occurrence,

PRIq – Priority ratio of defect importance.

The exemplary guidance indispensable for defining the Priority ratio of defect occurrence have been compared in the Table 1.

The risk connected with the occurrence of the environmental impact has been described as the dependence between the regularity of the environmental aspect and impact occurrence and its importance and expressed as:

$$URRe = PROe \cdot PRIe \qquad (2)$$

where the following means:

URRe – Environmental unit risk ratio,

PROe – Priority ratio of environmental aspect occurrence,

PRIe – Priority ratio of environmental impact importance.

The exemplary guidance indispensable for defining the Priority ratio of environmental aspect occurrence (PROe) describing the frequency of occurrence and the importance of the environmental impact have been compared in the Table 2.

Table 1 **Comparison of the guidance for the Priority ratio of defect occurrence – PROq.**

PROq	Criteria of the estimation
1 very low	Incidental cases of occurrence of the defect connected with the similar processes, process under the statistical control; Cp > 1,33, P < 0,0063 %
2 low	Sparse defects accompanying the similar processes, low possibility of the fault's source occurrence, process under the statistical control; Cp > 1,00, P < 0,27 %
3 moderate	The occurred defects accompany the similar processes, the source of the incompatibility occurs from time to time, process under the statistical control; Cp > 0,83, P < 1,25 %
4 high	High level of the defects occurrence, source of the incompatibility is of the repetitive character, process beyond the statistical control; P ≈ 5 % ÷ 12,5 %
5 very high	Occurrence of the defects almost or totally unavoidable; P ≈ 50 % ÷ 100 %

Table 2 **Comparison of the guidance for the Priority ratio of environmental aspect occurrence – PROe.**

PROe	Criteria of the estimation
1 very low	Occurrence of the environmental aspect improbable, there have never been any aspects connected with the similar processes
2 low	Occurrence of the environmental aspect of little probability, rare short-time cases of the environmental aspect occurrence linked with the similar processes
3 moderate	Occurrence of the environmental aspect probable, there have been cases of the environmental aspect occurrence
4 high	Occurrence of the environmental aspect highly probable, there have been cases of the long-lasting and numerous environmental aspect occurrence
5 very high	Occurrence of the environmental aspect almost unavoidable, the environmental aspect occurrence is always present

RESULTS IN THE STEEL CONTINUOUS CASTING PROCESS

The developed methodology of the identification of the key operational features has been verified for the continuous casting process.

Among the potential defects within the process one has identified the following:

- internal cracks: near the coigns, cornerways, oblongly, middle area, starry and edgy on the grains,
- other internal: axial porosity, axial rarity, systolic cavity, piercings and bubbles, stripe inclusions,
- surface: oscillatory wrinkles, scratches, piercings, dents, drawnings,
- dimension and shape: improper dimensions, rhombusness,

- concast slabs' cracks.

According to the undertaken methodology the mentioned above have been estimated, and the selected effects have been presented in the Table 3.

Table 3 **Comparison of the results of the exemplary defects assessment in the continuous casting process.**

Defect	Effect of the defect	PRO	PRI	URR
Deformation of shape and dimension	Rejection of the product or the necessity of additional processing	2	2	4
Cracks of concast slabs	Rejection of the product	1	5	5
Scratches	Necessity of removing the surface defects	2	1	2

Among the environmental aspects one has listed the following:

- emission of: the particulate matter, the sulphur dioxide, the nitrogen dioxide, the carbon monoxide, the carbon dioxides,
- occurrence of the waste – as scrap and iron oxides, cinder and the municipal ones,
- electricity, water and raw material intake,
- natural and high methane content gas combustion,
- noise emission,
- used-up oils and lubricants occurrence,
- industrial accident – liquid steel.

The results of the selected environmental aspects have been presented in Table 4.

Table 4 **Comparison of the results of the exemplary environmental impacts' assessment in the continuous casting process.**

Environmental aspect	Environmental impact	PRO	PRI	URR
Emission of the nitrogen dioxide	Pollution of the air with the nitrogen dioxide, acid rains and soil acidification	4	4	16
Used-up oils and lubricants occurrence	Storage and utilization	2	4	8
Raw material intake	Waste – as used-up ceramic moulding	2	1	2

The defects as well as the environmental aspects of the key-character has been pointed with taking into consideration the accepted at this level of analyses – the maximum value of the Priority numbers as well as the values of the Unit risk ratio, calculated on the basis of the formula (1), (2), higher than approved as the acceptable ones. It has been compared in the Table 5. For the analyzed process the maximum value of the Priority numbers have been defined as PRO/PRI = 5. The maximum acceptable value of the Unit risk ratio of the quality and environment has been described and leveled at URRq\URRe ≥ 15.

CONCLUSIONS

Both high values of the Unite risk ratio, higher than the described as the maximum ones, and critical values of the Priority numbers have allowed for the identification of the key-technological features.

Within the range of the quality operational features towards the defects, which are attached to the higher values of the Unite quality risk ratio and/or critical values of the Priority numbers of the occurrence or importance, one has qualified the following:

- diagonal cracks (URRq = 15, PRIq = 5),
- oblong cracks (PRIq = 5),
- middle area cracks (URRq = 15, PRIq = 5),
- starry cracks (PRIq = 5),
- edgy on the edge cracks (PRIq = 5),
- piercings and bubbles (URRq = 15, PRIq = 5),
- interjection of hydrogen (PRIq = 5),
- concast slabs' cracks (PRIq = 5).

Within the fulfillment of the environmental requirements, the highest values of the Environmental unit risk ratio and the critical values of the Priority numbers, the following aspects have been described:

- emission of the particulate matter (URRe = 16),
- emission of the sulphur dioxide (URRe = 16),
- emission of the nitrogen dioxide (URRe = 16),
- emission of the carbon monoxide (URRe = 16),
- emission of the carbon dioxides (URRe = 16),
- occurrence of the waste – as scrap and iron oxides (PROe = 5),
- noise emission (PROe = 5),
- electricity intake (URRe = 15, PROe = 5),
- water intake (URRe = 15, PROe = 5),
- other waste, including the municipal ones (PROe = 5),
- industrial accident – liquid steel (PRIe = 5).

Table 5 **Comparison of the technological features of the key-character in the process of the continuous casting.**

Key-technological features	Determinants of the key-character	
Quality operational features	URRq	PRO/PRI
Cornerways cracks	15	5
Oblong cracks	-	5
Middle area cracks	15	5
Starry cracks	-	5
Edgy on the grains cracks	-	5
Piercings and bubbles	15	5
Interjection of hydrogen	-	5
Concasts' cracks	-	5
Environmental operational features	URRe	PRO/PRI
Emission of the particulate matter	16	-
Emission of the sulphur dioxide	16	-
Emission of the nitrogen dioxide	16	-
Emission of the carbon monoxide	16	-
Emission of the carbon dioxides	16	-
Occurrence of the scrap and iron oxides	-	5
Noise emission	-	5
Electricity intake	15	5
Water intake	15	5
Occurrence of the other waste	-	5
Industrial accident – liquid steel	-	5

The pointed defects and the environmental aspects – being the critical technological features of the continuous casting process – should undergo a detailed control. It should take into account not only the current process' monitoring but also the preventive actions taken as the reactive ones.

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