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Pilot tests of the advanced system of process diagnostics in PKN ORLEN

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Zatrudniony jest w Instytucie Automatyki i Robotyki, Politechniki Warszawskiej. Prowadzi badania z zakresu diagnostyki procesów przemysłowych i systemów mechatronicznych oraz układów sterowania tolerujących uszkodzenia. Kieruje pracami badawczymi, których rezultatami są opracowanie i przemysłowe aplikacje systemów zaawansowanego monitorowania i diagnostyki. Członek Komitetu Automatyki i Robotyki Polskiej Akademii Nauk.

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Zatrudniony jest w Głównym Dziale Automatyki w PKN ORLEN S.A. Ma bogate doświadczenie oraz wiedzę ekspercką w zakresie inżynierii, rozruchów oraz oddawaniu do eksploatacji, wykrywaniu i usuwaniu usterek oraz utrzymania w ruchu systemów automatyki. Odpowiedzialny jest za standardy i procedury utrzymania ruchu oraz dostępność systemów monitorowania, sterowania oraz ESD.

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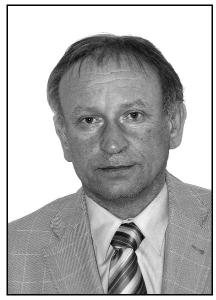

Abstract

The paper presents the application of the AMandD system for the purpose of monitoring of the coke sedimentation process and current diagnostics of measuring paths and control valves in the hydrocraking installation in the PKN Orlen refinery. First, short description of the AMandD system and the diagnosed installation is given. Next, the structure of the AMandD system is summarized. Then, the summary of applied methods for monitoring of the slow changes in the process and conducting current diagnostics are given.

Keywords: fault detection and isolation, industrial processes, diagnostic system, process state monitoring.

Pilotażowe testy zaawansowanego systemu diagnostyki procesów w PKN ORLEN

Streszczenie

W artykule opisano aplikację system AMandD do monitorowania procesu koksowania oraz realizacji bieżącej diagnostyki torów pomiarowych i zaworów regulacyjnych instalacji hydrokrakingu w rafinerii PKN Orlen. Najpierw przedstawiono ogólny charakterystykę system AMandD oraz opis instalacji technologicznej. Następnie podsumowano moduły system wykorzystane w opisywanej aplikacji oraz przedstawiono ogólną charakterystykę zastosowanych metod bieżącej diagnostyki oraz monitorowania powolnych zmian parametrów procesu.

Słowa kluczowe: detekcja i lokalizacja uszkodzeń, procesy przemysłowe, systemy diagnostyczne, monitorowanie stanu procesu.

1. Introduction

The faults of process components, measurement devices and actuators as well as operator errors are unavoidable in the technological installations of power, chemical, metallurgical, food and many other industries in spite of usage of highly reliable equipment components. They can arise in an abrupt or incipient manner [1-3].

Abrupt faults cause substantial and long-term disturbances of the production process course leading to its efficiency decrease and sometimes even to the process stop. The economic losses are very high in such cases. Some of the faults lead to failure states, e.g., process installation destruction, environment pollution and can even cause life hazard.

Beside, catastrophic failures of technological components, incipient destructive changes often take place. They change the process characteristics and decrease its functional quality indices. Such changes can be caused by such phenomena as processes of degradation of materials, sedimentation of different kinds of substances on equipment parts, etc. Periodical inspections and maintenance are carried out in order to counteract the consequences of such effects and to prevent the faulty states occurrence. Process interruption in order to carry out the inspection and necessary maintenance work leads to high production losses and high maintenance costs. Lengthening the period between maintenances can lead to machinery and equipment breakdowns and, in the case of hazardous technological installations, even to disaster. The only rational way of proceeding is to replace periodical inspections and maintenance by the strategy of maintenance planning based on the current evaluation of the process technological state.

The tasks of process diagnostics are, so far, realised by: maintenance stuff, system of vibro-acoustic diagnostics and modules of alarm signalling in the DCS and SCADA systems. The systems of vibro-acoustic diagnostics are useful mainly for supervision of rotating machinery. The alarm thresholds control used in the DCS and SCADA systems has many disadvantages, like: great number of alarms signalled in short period of time in the case of dangerous fault forming, the lack of possibility to detect many parametric faults (in respect to compensating action of control loops), large detection delays and the reasoning mechanisms allowing fault isolation [3]. The above features make it difficult to formulate the diagnosis by the operators, i.e., to recognise the cause of appearing of the set of visible alarms. Such diagnosis is, in many cases, necessary to undertake proper protecting actions. Therefore proper diagnosis formulation depends only on the operator's knowledge, experience and psycho-physical state.

The development works focused on diagnostics systems for industrial processes were caused by imperfections of alarm signalling systems and the need for quick and precise recognition of abnormal and faulty states.

The advanced monitoring and diagnostic system AMandD developed in the Institute of Automatic Control and Robotics, Warsaw University of Technology, is one of the first of such solutions. It is dedicated for applications in power, petrochemical, chemical, metallurgical, food and other industries. The system is the unique solution in the global scale in respect to its functionality. The advanced process diagnostics in the AMandD system utilises modelling and dynamic process identification methods, methods of knowledge engineering and the techniques of artificial intelligence: neural networks, fuzzy logic and genetic algorithms [4-8].

2. System AMandD

AMandD is a distributed system, working on standard PC machines with the MS Windows operating system. It is adjusted to cooperation with different decentralized control systems (DCS), as well as with the systems of supervision and monitoring of processes (SCADA). Process data are collected from the control system (or appropriate available process data warehouse like PI OSI-SOFT system or iHistorian) with the use of industrial data exchange standards like OPC client-server communication.

The main task of the AMandD system is the early and precise detection of faults of control valves, measurement paths and technological devices, as well as the monitoring the degradation degree of technological apparatuses. In the abnormal and faulty states, the system assists the process operators by passing them the generated diagnosis about the existing faults and, if possible, advisory messages informing about necessary preventing actions to be undertaken. The diagnosis specifies the process state much more precisely than the sequences of alarms generated by modern control systems. Moreover, the system is equipped with an advanced tool for the process modelling. It makes the creation of software sensors and analysers possible. Thanks to the extended variable processing module, it is also possible to build the process simulators based on the AMandD system [4, 8].

3. Pilot tests in PKN ORLEN

3.1. Diagnosed equipment

Pilot tests of the AMandD system were conducted in the PKN ORLEN refinery on H-Oil plant (HOG). The tasks of the system are as follows:

- monitoring of the coking degree of the technological apparatus: vacuum heater H302 and distillation column C303,
- early detection and isolation of the measuring devices and control valves faults within the sections of the vacuum oven H302 and distillation column C303.

The aims of the system application were:

- the implementation of the maintenance strategy based on the current evaluation of the technological installation state,
- hazard limitation of dangerous and faulty states appearing in the installation, and shutdowns that result from these states.

The main process purpose is to conduct the desulfurization of the feed medium (the heavy remainder left from crude oil), and cracking it to light, more valuable products. In the processing of the raw material, the phenomenon of the derivative material sedimentation on the process technological devices and apparatus takes place (mainly coke).

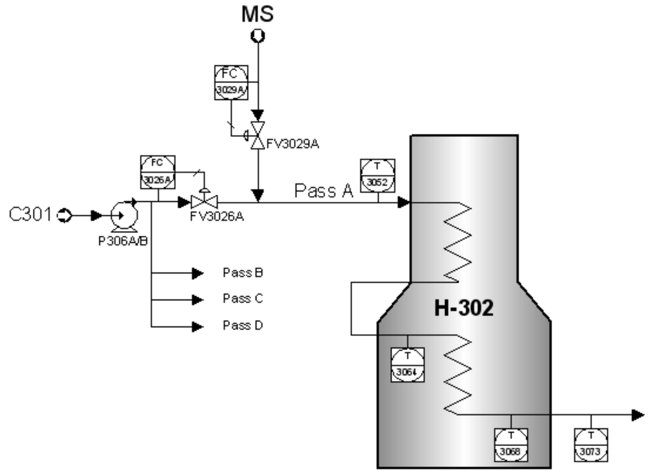

Fig. 1. Simplified diagram of mazout transport in the vacuum heater H302 (only one of four coil pipes is presented)
Rys. 1. Uproszczony schemat transportu mazutu w piecu próżniowym H302 (pokazano tylko jedną z czterech wężownic)

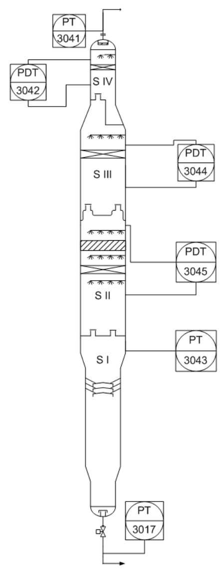

Fig. 2. Diagram of distillation column C303
Rys. 2. Schemat kolumny destylacyjnej C303

The two subsections of the whole H-oil plant were defined to conduct detailed research. The first one was the vacuum heater, and the second one was the distillation column. Fig. 2. presents the simplified diagram of one of the four medium passes in the vacuum heater H302. The mentioned above process of coke sedimentation can lead to: incorrect heat exchange in heater passes and exchangers, problems in vacuum tower and other equipment operation, wrong temperature and level indications and finally to the disturbances in the main process.

In the column of vacuum distillation product, the desulfurization and its final preparation for the thermal-electric power station takes place. The places where the influence of coke sedimentation is most visible are the structural packages in vacuum tower at the bottom of the column with the heaviest oil fractions (Fig. 2). The coke sedimented on the structural packages causes the deterioration of lighter fractions flow at the top of the column. It finally leads to worse output of additional products.

The coke accumulate at the bottom of the column. It is also observed in the degree of coking of the equipment of the particular section. The degradation caused by coke sedimentation is a reversible process. But the cleaning procedure of the installation and instrumentation equipment requires installation shutdown and complete process switch off. In respect to high cost of such operation, it is realized periodically, during the scheduled turnarounds. Quite often, the process still runs even if the service personnel are aware of the increased degree of the installation degradation. During such situations, the need for evaluating in an on-line mode, the coke sedimentation degree and predicted remaining time to achieve critical state arises.

3.2. System structure

Several AMandD system modules are utilized in the configuration for the HOG application. Each module realises particular constituent system tasks. Block diagram of the system is presented in Fig. 3. The following modules and realized tasks can be distinguished:

- PILink. Process data from the DCS system are collected by the PI-OSI-Soft system which is a factory global data distribution system. The AMandD system collects the data from the PI server through the dedicated bridge PILink. All the process data are collected with the 60 seconds sampling time.
- PExSim-Preproc. Calculation module working with the 60 seconds sampling time. This module calculates average signals and re-samples data for the purpose of the proper coking analysing module.
- PExSim-Incipient. Module responsible for calculating the current values of coking coefficients and the predicting time left to archives the critical process parameters. This module works with the 480 seconds sampling time.
- InView-Incipient. Operator graphical interface module. Current and predicted process state are shown in specially designed mimics.
- SVArchiviser. Module responsible for storing the processed data in an archival database. With the use of data from the database, the operators can analyze historical process states.
- PExSim-FDI and iFuzzyFDI. Modules responsible for implementation of on-line FDI procedures (classical fault detection and isolation). Elaborated diagnosis is visualized with the use of the dedicated operator graphical interface InView-FDI.

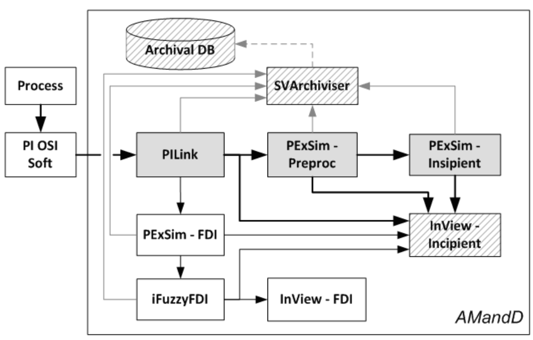

Fig. 3. Structure of the AMandD system used in the HOG application
Rys. 3. Struktura systemu AMandD zastosowana w aplikacji dla HOG

3.3. Installation coking degree monitoring

The algorithm of the estimation of the time remaining to reach the critical coke sedimentation degree in the process is based on several proposed coefficients, different for each part of the process. The tests calculation coefficients for the oven use the relations from heat exchange. In the case of ideal installation working conditions (no coke sediment), the heat exchange coefficient should keep a constant level. It results from constant values of the heat exchange resistances (thickness of pipe walls, etc.). When the sedimentation inside the pipeline progresses, the heat exchange resistance should increase.

The tests conducted for the distillation column are based on the comparison of the pressure drop along the whole column with the pressure difference between the outlets of the sections SI and SIV. The tests and its derivative enable to validate the flows of lighter fractions towards the top of the column and the clogging of particular structural packages (e.g. PDT3045).

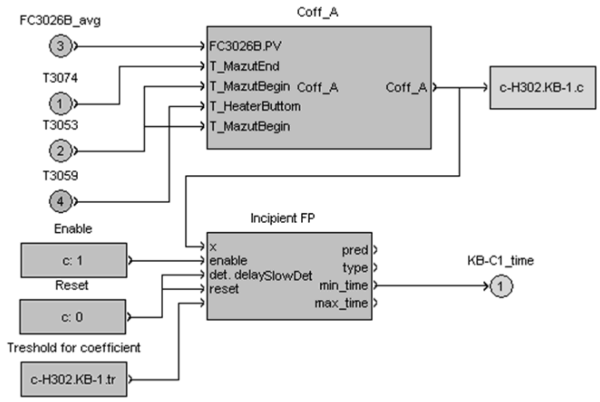

Fig. 4. Block diagram (graphical representation in PExSim module) of the algorithm used to calculate the coking degree coefficient and the time remaining to reach critical process degradation level for the column C303
Rys. 4. Schemat blokowy (reprezentacja graficzna w module PExSim) algorytmu wyznaczania współczynnika zakoksowania oraz czasu pozostałego do osiągnięcia krytycznego stanu degradacji dla kolumny C303

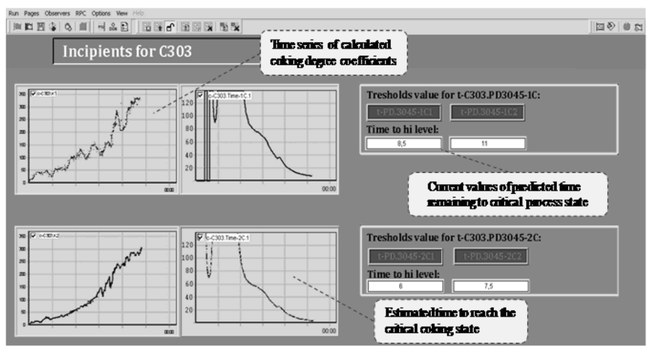

Fig. 5. Operator's graphical interface for the column C303
Rys. 5. Interfejs graficzny operatora dla kolumny C303

Fig. 4 shows exemplary block diagrams of the algorithms of determining the calculation of the coking degree coefficients. They are constructed during the configuration stage based on available function blocks in the calculation environment PExSim.

Calculated coefficients of the coking degree as well as predicted remaining time to reach critical process state are visualised in specially prepared operator mimics in visualisation module InView. This module enables us to create graphical user interfaces dedicated for the diagnostic purpose for the operators and the maintenance stuff. The operator screens are divided thematically into sections corresponding to the column C303 and heater H302. Exemplary screen for column C303 is presented in Fig. 5.

3.4. Detection and isolation of measuring devices and actuators faults

System AMandD utilises methods based on analytical, neural and fuzzy models, as well as heuristic methods making use of different relations between the process variables for the fault detection. These methods allow us to detect a much higher number of faults than the classical alarm system [1-3]. The sensitivity of the model-based methods is an additional advantage. It makes it possible, in many cases, the early detection of a small size fault, before its negative consequences appear. In such cases, it is possible to undertake proper protective or maintenance actions that limit the consequences and losses caused by faults.

The algorithms of diagnostic tests are configured with the use of function blocks in the PExSim module (see Fig. 6). Fault detection with the use of models of particular signals consists in the evaluation of so called residuals, i.e., the differences between the value of a measured signal and the model output. In the normal state, the residual value is close to zero. When the fault appears in the controlled part of the system, the residual value varies from zero – the fault symptom is observed. Fig. 7 presents the exemplary results of a residual based on the process model that reconstructs one of the process variables.

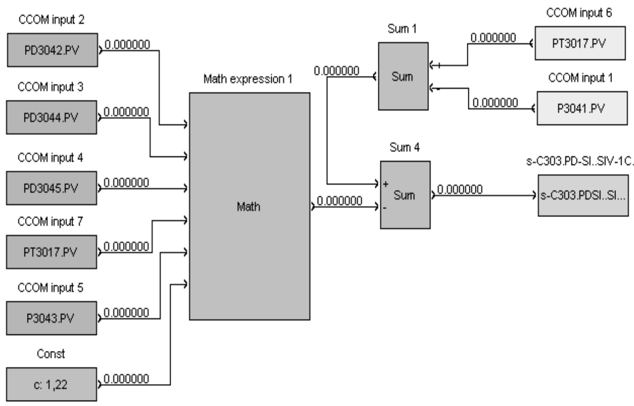

Fig. 6. The example of diagnostic test configured from functional blocks
Rys. 6. Przykład testu diagnostycznego skonfigurowanego z bloków funkcyjnych

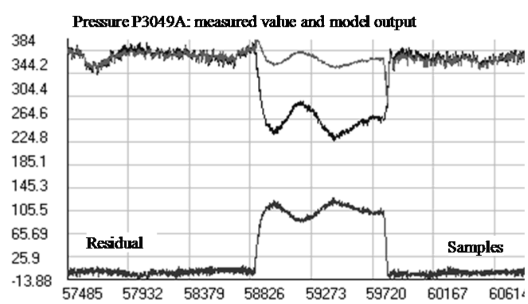

Fig. 7. The time series of pressure P3049A: measured and model based reconstructed values, residual
Rys. 7. Przebieg ciśnienia P3049A: wartość rzeczywista i odtwarzana na podstawie modelu, residuum

The heuristic methods allow us to write down the additional knowledge about proper (normal) installation functioning in the diagnostic system. These methods utilise relatively simple dependences between the process variables, e.g., the relations between temperatures in different parts of the steam draft of a power boiler. Such dependences are not appreciated and omitted during the alarm systems creation. Meanwhile, the design experience shows that they are a very essential and reliable source of knowledge about the process state and present faults. The knowledge about such relations is very often possessed by the process and control engineers as well as operators. System AMandD delivers the tools for its formal writing down and utilising in the current process diagnostics. Residual values and the results of diagnostic tests are the outputs of detection algorithms. They are a subject of two- or three-value fuzzy evaluation.

Fuzzy residual values evaluation makes it possible to take into account the uncertainties connected with modelling errors, disturbances, measurement noises and the difficulties in defining threshold values. Two-valued fuzzy evaluation of absolute residual value is used in the simplest case. Three-valued evaluation additionally takes into account the residual sign. It can increase fault isolability [3]. As a result of fuzzy residual evaluation, one gets fuzzy diagnostic signals. The value of a fuzzy signal is determined by the values of the membership function of all fuzzy sets calculated for the particular residual value.

The parameters of fuzzy sets can be determined based on the experiment and the expert's knowledge. System AMandD enables us to calculate these parameters automatically based on the analysis of statistical parameters of residual values recorded during the process run in the normal state.

Fault isolation is conducted based on current values of the set of diagnostic signals (observed symptoms) and written down as the knowledge base relation between faults and symptoms. This relation takes the form of rules:

$$if\left(s_j = v\right) then\left(f_k \; or \; f_n \; or \ldots or \; f_r\right) \quad (1)$$

where: s_j denotes the j^{th} diagnostic signal, v – value of the diagnostic signal (fuzzy set), f_k – k^{th} fault.

The reasoning is realised according to the iDTS method (Industrial – Dynamic Table of States) designed in the Institute of Automatic Control and Robotics, Warsaw University of Technology. The iDTS method is based on the fuzzy logic. The elaborated diagnosis points out particular faults together with the certainty factors of their existence.

Elaborated diagnosis can be presented directly by the specialised modules of the AMandD system or can be transmitted to the SCADA or DCS system. The indicators corresponding to particular faults are placed on the process mimics, next to the related measurements or the equipment elements. They display fault certainty factors that vary in the range 0-1. If the certainty factor value is high than the bar representing this value has a red colour. In the case of lower values, its colour changes to orange, than yellow and finally it becomes white.

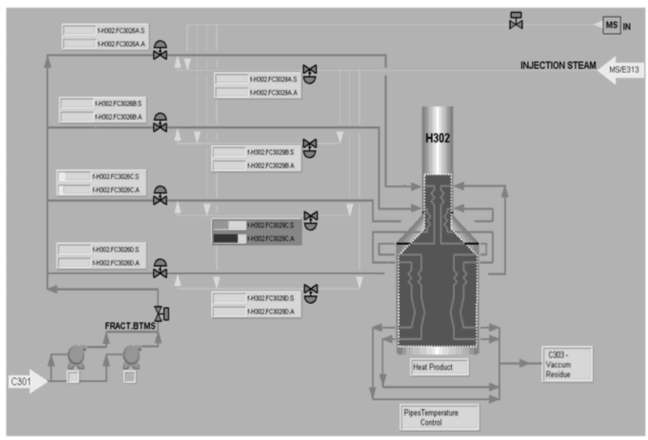

Fig. 8. Fault visualisation in the AMandD system: faults of control valves and measuring paths of mazut and steam flow – oven H302 section
Rys. 8. Wizualizacja diagnoz w systemie AMandD: uszkodzenia zaworów regulacyjnych oraz torów pomiarowych przepływu mazutu oraz pary - piec H302

4. Summary

The software for monitoring the degradation degree of the technological apparatus and prediction of the remaining time to achieve the critical state assists the service staff in making the decisions about necessary maintenances. It is a tool that allows us to implement the strategy of maintenance planning based on the current evaluation of the technical process state which can replace traditional, periodical maintenance. This strategy can allow us to increase the periods between maintenances, and to avoid achieving the situation in which the faulty states appear that are caused by the faster technological apparatus degradation than the one assumed. Application of this strategy increases safety of monitored processes. Additional benefits are related to lower maintenance costs.

Precise and quickly achieved diagnosis make us possible to conduct the necessary protecting actions. Therefore, the diagnostic systems together with the protecting actions play the role of the second, higher layer of the process protection system. Classical systems of technological blockages and standard protection systems are the first, lower level of the process protection system. Superior process protection layer gives us the possibility of the reduction or elimination of the fault consequences due to more precise and quickly achieved diagnostic information. This enables us to avoid the actuation of the lower level protection systems which usually would cause process stop or unnecessary drop of its efficiency.

5. Acknowledgments

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6. References

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Artykuł recenzowany

INFORMACJE

Studia Podyplomowe

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Celem studiów jest przekazanie wiedzy teoretycznej i umiejętności praktycznych w zakresie: projektowania, wdrażania i utrzymania ruchu systemów automatyki, programowania sterowników PLC oraz systemów nadrzędnych (SCADA), projektowania, programowania i eksploatacji automatycznych systemów pomiarowych w laboratoriach badawczych i przemysłowych, metod opracowania danych w systemach zapewnienia jakości procesów przemysłowych.

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Studia przeznaczone są dla pracowników o różnych specjalnościach, z wyższym wykształceniem o kierunku elektrycznym, elektronicznym, informatycznym lub pokrewnym, zajmujących się organizacją pomiarów w laboratoriach badawczych i przemysłowych lub eksploatacją oraz modernizacją systemów starowania. Ich ukończenie pozwoli uczestnikom na podwyższenie kwalifikacji niezbędnych do sprawnego opracowywania i wdrażania nowoczesnych systemów. Absolwent Studiów otrzymuje Świadectwo Ukończenia Studiów Podyplomowych w zakresie objętym nazwą studiów.

Studia prowadzone są na Wydziale Elektrycznym Politechniki Śląskiej w Gliwicach, w systemie zaocznym w każdą sobotę lub w co drugi weekend (do wyboru) przez dwa semestry. Zajęcia prowadzone są przez nauczycieli akademickich ze stopniem co najmniej doktora oraz przez zaproszonych Gości o uznanym dorobku i autorytecie. Studia obejmują 200 godzin dydaktycznych. Rozpoczęcie Studiów nastąpi po skompletowaniu odpowiedniej liczby kandydatów na dany rodzaj studiów.

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