АС-ДИАГНОСТИКА-КВТД and АС-ДИАГНОСТИКА-СВО Integrated Systems - as Modern Facilities of Transition from Scheduled Repairs of Rotating Machinery and High-Voltage Equipment to On-Condition Maintenance Technology.

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Modern knowledge and gained experience in the form of different data bases containing measurement results for operational parameters of rotating machinery and high-voltage equipment allow us to assert that a whole number of engineering and system problems in development of information technologies has been solved for today to create integrated systems providing a transition from scheduled repairs of rotating machinery and high-voltage equipment to the technology of on-condition maintenance of this equipment. Transferring equipment to the on-condition maintenance technology provides the trouble–free operation of the equipment. By processing data bases for measured parameters of technological equipment according to special algorithms we enable the service personnel to know how long the equipment can operate with the detected defect. Using the described –below integrated systems the personnel obtains enough on-line information to prolong trouble-free operation intervals and reduce the risk of equipment failure. These integrated systems save financial resources and personnel working time for maintenance and provide the capability of controlling the technical state of the rotating machinery and high-voltage equipment of the enterprise.

In our opinion, the integrated systems providing the transition from scheduled repairs to the on-condition maintenance technology should be only stationary. The correctness of our statement is supported by the fact that the human factor is excluded from making a decision on the technical state of the equipment. The systems mentioned above provide service personnel with information and instruments that enable them to make a decision on the state of the equipment described below. The АС-ДИАГНОСТИКА-КВТД and АС-ДИАГНОСТИКА-СВО Integrated Systems have been developed, tested and registered in the State Register of Measuring Means and Equipment of Ukraine with number UA-MI/1p-1995-2006. The integrated systems are operated in the petroleum-transfer stations "Жулин (Zhulin)", "Куровичи (Kurovichi)", "Гомель (Gomel)", "Защебье (Zaschebie)", "Туров (Turov)", "Кобрин (Kobrin)" of the ДРУЖБА (Friendship) international pertroleum pipeline and in the transformer substation of the AZOT Public Corporation, Cherkassy. The АС-ДИАГНОСТИКА-КВТД integrated system has been also registered in the State Registers of Measuring Means and Equipment of the Republic of Belarus with No. 4762 and of Russian Federation with No. 27879.

Objects for Enhanced Monitoring and Diagnosis and Detected Defects:

Rotary Equipment ─ АЗМВ-type asynchronous and СТД-type synchronous electric motors of 6 kV voltage and power from 2.5 MW and greater, tooth and plate clutches, pumps, compressors, fans, et al., actuators, for example, excavation combine reducers. The measured parameters are as specified in the standards [4].

The detected defects are the securing on and the condition of the foundation, the condition of rolling bearings (defects of the rolling elements, retainer, the correctness of assembling and mounting) and slider bearings (clearances and oil vibrations), disalignments, out-of-balance.

Substation High-Voltage Equipment: ─ power 3-phase transformers of 750-220-110\35\6 kV operating voltage and power of 25,000 kVA and greater; 110 kV measuring current transformers; power 3-phase reducing transformers of 6\0.4 kV operating voltage and 1,000 kVA power; 5АЗМВ-4000 explosion-proof asynchronous electric motors of 6 kV operating voltage and 4000 kW power; СТД-5000-2 synchronous electric motors of 6 kV operating voltage and 5000 kW power; 6 kV supply line feeders for electric motors and 6\0.4 kV transformers; EXLIM-P096-AN123 overvoltage suppressors of 110 kV operating voltage.

The measured parameters and detected defects are as follows:

Checked Parameter	Used Checking Method
Condition of the primary insulation	Measurement and analysis of partial discharges in the transformer insulation; the parameters: partial discharge intensity (**PDI),** magnitude **(Q_{02})**, summary partial discharge pulse quantity **(SumPD)**. Detection of the defect type; Correlation of the partial discharge intensity and detected defect type with chromatography data.
Lead terminal condition checking	Lead terminal conductivity current checking. Transformer disconnection in case of before-alarm condition; Partial discharge checking.
Phase winding resistance checking	Measurement and analysis of current in the transformer neutral wire. Detection of winding insulation unsymmetry appearing in case of a breach of the winding shape after an impact of short-circuit currents.
Cooling system operation checking	Checking for difference in the temperatures of the upper and lower parts of the transformer tank, allowing for the load and environment temperature.
<u>Gas-chromatography analyses of gases dissolved in the oil</u> (H_2 – hydrogen, CH_4 – methane, CO_2 – carbon dioxide, C_2H_6 – ethane, C_2H_4 – ethylene, C_2H_2 – acetylene, CO – carbon monoxide, O_2 – oxygen) and moisture content.	Destruction of the oil-barrier insulation in the tank; the condition of the winding insulation of phases A, B, C; an arc in the oil, the solid insulation is not affected; thermal decomposition of the oil; thermal decomposition of the oil-barrier insulation; pyrolysis of the cellulose insulation; pyrolysis of the oil.

From the viewpoint of the hardware and software design architecture – the Integrated Systems are realized according to a distributed design architecture. The structure of the software-engineering complex of the automatized diagnosis system has an open three-level architecture both for the interface channels and for the software and hardware sets and makes it possible to extend the functional capabilities of the Integrated Systems by adding new sensors, controllers, signal processing and new-object diagnosis algorithms. Two independent enhanced monitoring systems both for vibration-based diagnosing of rotary equipment and for diagnosing of high-voltage equipment operate under the control of the *Windows XP*™ operating system. Provision is made to integrate these Systems into the existing automated control systems and computer-integrated technological process control systems of the enterprise.

The upper level of the Integrated System represents an operating station and is developed on the basis of an industrial computer fitted with a dual-core processor, 1 GB random-access memory, RAID controller and hard disks up to 300 GB in storage capacity and high-performance industrial local network systems based on the CAN and RS-485 industrial interfaces (ModBus RTU protocol).

All smart controllers (or subsystems) included into the lower level of the Integrated System are designed to be installed on power high-voltage equipment with an operating voltage of 6 up to 750 kV and operate within a temperature range from - 40 ºC up to 120ºC. The term “smart” is used in this case because these devises are fitted with built-in processors, storage memories, interface ports and simplified displays. In addition, these controllers perform signal processing: amplification, normalizing, digital conversion, fast Fourier transformation (FFT) and filtering. The algorithms loaded into the controller memory provide desired-signal extraction and noise elimination. By using the settings entered into the controllers the equipment protection relay is activated, which gives the right to use the term “smart”.

Each controller is linked with the upper level through the CAN or MODBUS RTU protocol (the RS-485 interface). Therefore, the term “smart” is quite applicable to the controllers used in the integrated systems. To provide the reliability of the integrated system all controllers are autonomous systems, i. e. if the **I** (upper) level of the integrated system fails, the **II** (lower) level will provide equipment condition monitoring and equipment protection. The event and data archives two years long stored in the controller memory make it possible to perform on-line diagnostics and prediction of the service life of diagnosis object at the upper (first) level of the Integrated Systems.

The technical state of rotating machinery equipment is characterized by the following criteria: vibration velocity root-mean-square value trend, peak factor, phase, input current **I** and consumed power **W** spectra, vibration velocity and vibration acceleration spectra. By using these criteria the shaft disalignment, rotor out-of-balance, the condition of rolling bearings and slider bearings are diagnosed.

The technical state of high-voltage equipment is characterized by the following criteria: variation of the lead-insulation dielectric-loss tangent ***tgδ,*** lead capacity **C1,** leakage current I_L, partial discharge magnitude Q_{02}, partial discharge intensity PDI, ambient air humidity **H**, temperature **T**, amount (**ppm**) of gases dissolved in transformer oil (up to -8). By using the main above-mentioned criteria the technical state of transformers, the feeder insulation of electric motors, the winding insulation of hydroelectric turbogenerators and electric motors is diagnosed.

The Integrated Systems perform continuous enhanced technical-state monitoring of equipment and the results of the monitoring are presented in a diagnostic information readout (see Fig. 2-5), on the basis of which the maintenance is performed only at that time and in that place when and where the maintenance is absolutely necessary. The simplified block diagram of the Integrated Systems is shown in Fig. 1.

The enhanced monitoring system includes:
- regular technical-state monitoring (checking) of equipment;
- searching for defects and faults;
- defect threat level determination;
- evaluation of the remaining service life of equipment.

The Integrated Systems are positioned in accordance with the design performance and functional completeness specifications as a realizing method of technical diagnostics in the FUNCTIONAL group [1] with addition of the methods of the Compositional Analysis and Non-electric Magnitude Measurements. The diagnostic processors of the Integrated System are designed according to a classical scheme:

Measurement Data Base →Knowledge Data Base→Obtained Information Processing and Result Displaying→Generation and Storing of Monitoring and Diagnosis Results.

A peculiarity of creating data bases of stationary monitoring and diagnostic systems is the fact that their data bases are compatible with measurement data bases of portable instruments and can be supplemented with measurement data from such instruments.

When developing the Integrated Systems and defining their functional completeness, we proceeded from information on faults and failures [2] in transformer equipment, the Customer's technical requirements, the requirements specified in the standard [4] and the experience of operating the АС-ДИАГНОСТИКА-КВТД Integrated System at the Customer's objects. Among these objects the main ones are:

1) Electric motors: types - 5АЗМВ-4000, ТДНР-1600, СТД-2000, СТД-2500 ВАО-800.
2) Pumps: types - НМ-7000-210, НМП-3600x78, НМП-2500, NG 300/460/100, ZML 400/600.
3) Power 3-phase reducing transformers for 110\35\6 kV voltage and 25,000 – 50,000 kVA power; power 3-phase reducing transformers for 6\0.4 kV voltage and 1,000 kVA power;
4) 110 kV measuring current transformers;
5) Supply line feeders of 6 kV electric motors and 6\0.4 kV transformers;
6) Overvoltage suppressors (OVS):
   EXLIM-P096-AN123 for 110 kV voltage, EXLIM-0051-CH052 for 35 kV voltage;
7) Condition of the lead terminals of 110 kV transformers (**tgδ**, capacity **C**);
8) Moisture content of oil 0-100% at a temperature of 25°C;
9) Dissolved-gas content of oil: (H_2 - hydrogen, O_2 - oxygen, C_2H_2 – acetylene, C_2H_6 - ethane, CO – carbon monoxide).

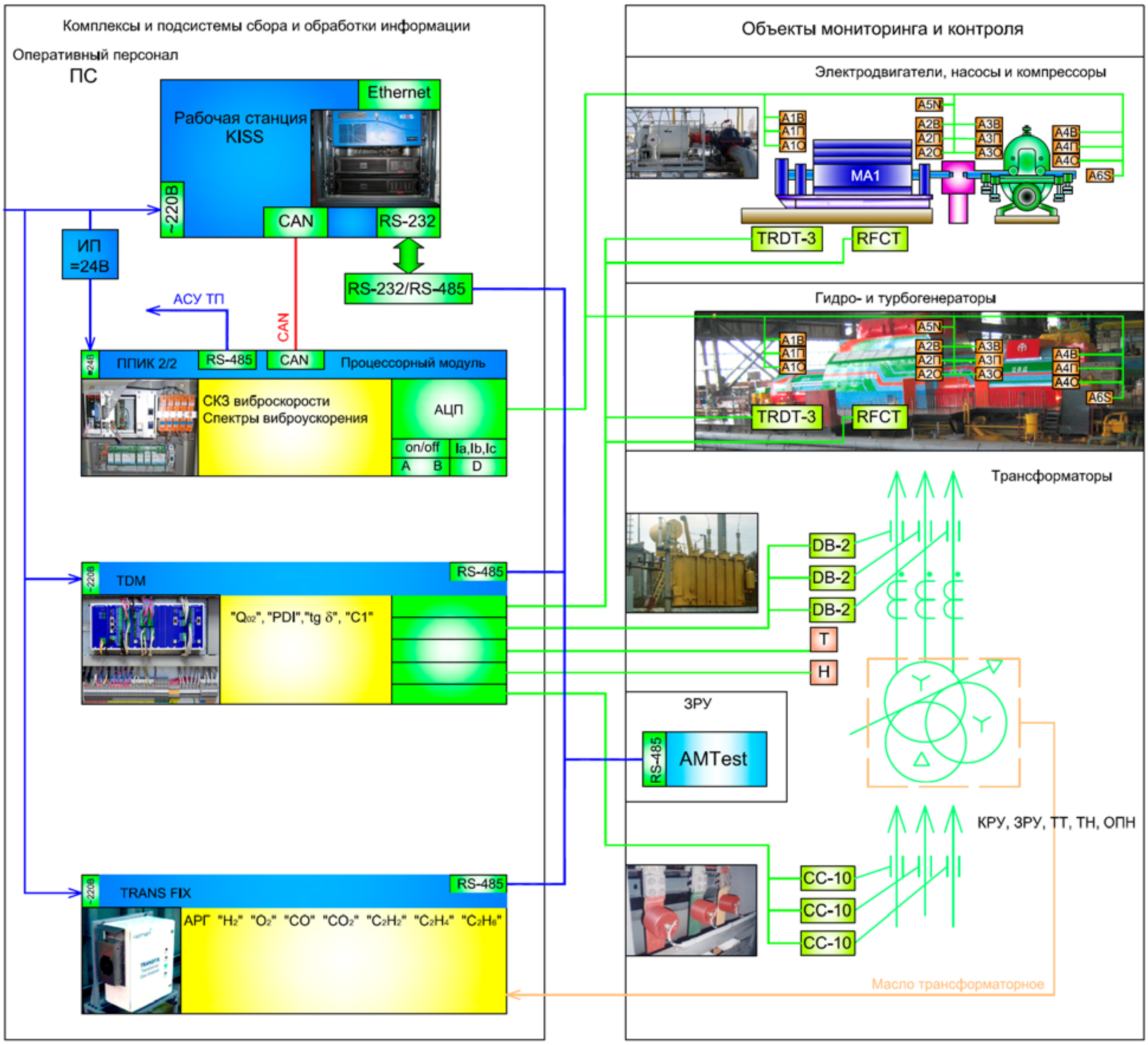


Fig. 1. Simplified Block Diagram of Integrated Systems

Conventional abbreviations and legends shown in Fig. 1.: Комплексы и подсистемы сбора и обработки информации – data acquisition and processing integrated systems and subsystems; Оперативный персонал – operating personnel; Рабочая станция – working station; KISS – system unit of the working station with application software for monitoring and diagnostics; CAN – industrial controller area network for transferring vibration data of rotary units; ПС – power and high-voltage equipment substation; АСУ ТП - computer-integrated technological process control system; Процессорный модуль – processor module; СКЗ виброскорости - vibration velocity root-mean-square value; Спектры виброускорения - vibration acceleration spectra; АЦП - analog-to-digital converter; Объекты мониторинга и контроля – monitored and checked objects; Электродвигатели, насосы и компрессоры – electric motors, pumps and compressors; Гидро- и турбогенераторы – hydro- and turbogenerators; Трансформаторы – transformers; ЗРУ – indoor switchgear; AMTest – instrument for diagnosing rotary machines by the consumed current and power spectra; ППИК-2/2 – controller (subsystem) for acquiring and processing data from vibration sensors (accelerometers); TDM – controller (subsystem) for acquiring and processing data from partial discharge and leakage current sensors; TRANSFIX – subsystem for analyzing gases dissolved in transformer oil; T – temperature sensors in the transformer tank; H – ambient air humidity sensor; A, B, C, Д – vibration accelerometer sensors on rotary unit bearing supports; TRDT -3, RFCT, DB-2, CC-10 – partial discharge sensors for the stator windings of the turbo-hydrogeneror and electric motors, the neutral wire, 750-110/35/6 kV transformer lead terminals, buses, 6 kV feeders, current transformers, overvoltage supressors; `КРУ, ЗРУ, ТТ, ТН, ОПН – complex switchgear, indoor switchgear, current transformer, voltage transformer, overvoltage suppressor; Трансформаторное масло – transformer oil.

The operation results of the monitoring and diagnostic processors are shown in Fig. 2-5.

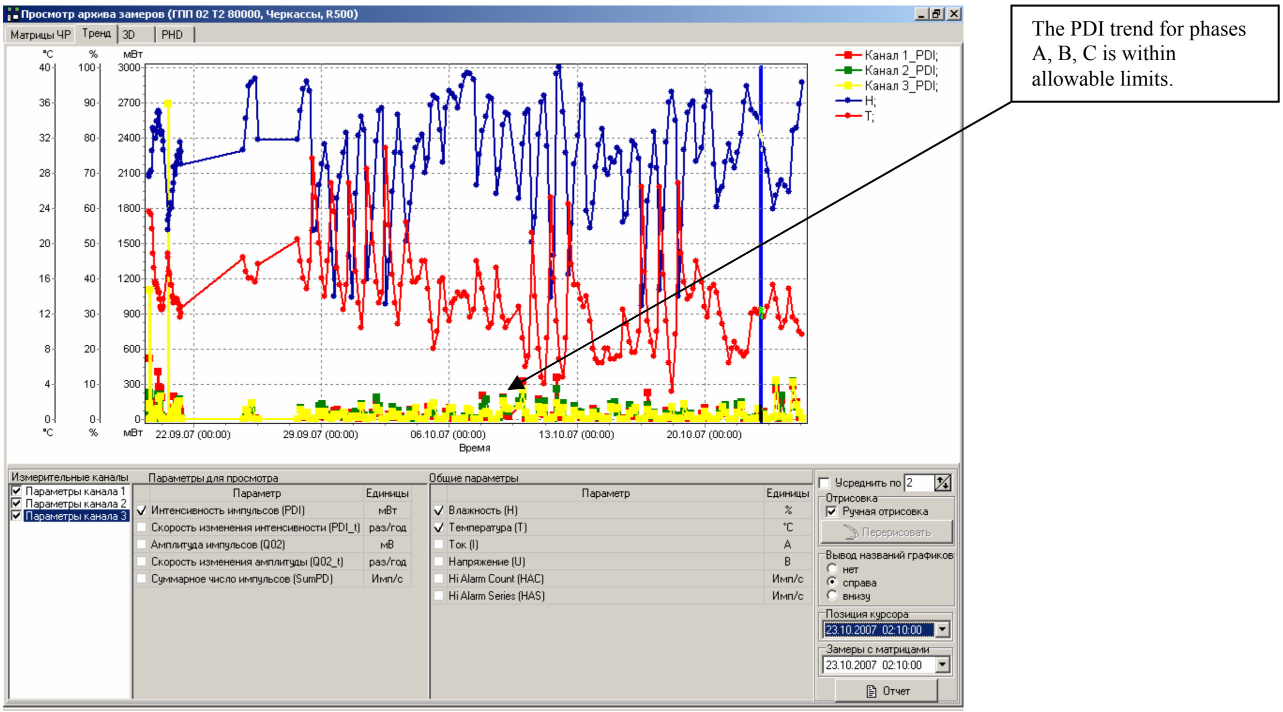


Fig. 2. Displaying Partial Discharge Intensity in 110 kV, 80 kVA Transformer of AZOT Public Company

Просмотр архива замеров (ГПП 02 Т2 80000, Черкассы, R500) - Looking through the measurement archive (Main Reducing Substation 02 T2 80000, Cherkassy, R500).

Матрицы ЧР	PD matrices	Общие параметры	General parameters
Тренд	Trend	Влажность	Humidity
мВт	mW	Температура	Temperature
Канал	Channel	Ток	Current
Время	Time	Напряжение	Voltage
Измерительные каналы	Measuring channels	A	A
Параметры канала	Channel parameters	B	V
Параметры для просмотра	Parameters for viewing	Усреднить по	Average out by
Параметр	Parameter	Отрисовка	Drawing
Интенсивность импульсов	Partial discharge intensity (PDI)	Ручная отрисовка	Manual drawing
Скорость изменения интенсивности	PDI rate	Перерисовать	Redraw
Амплитуда импульсов	PD pulse magnitude	Вывод названий графиков	Graph name displaying
Скорость изменения амплитуды	PD magnitude rate	нет	No
Суммарное число импульсов	Pulse summary number	справа	Right
Единицы	Units	внизу	Down
раз/год	time / year	Позиция курсора	Cursor position
имп/с	pulse / s	Замеры с матрицами	Measurements with matrices
		Отчет	Report

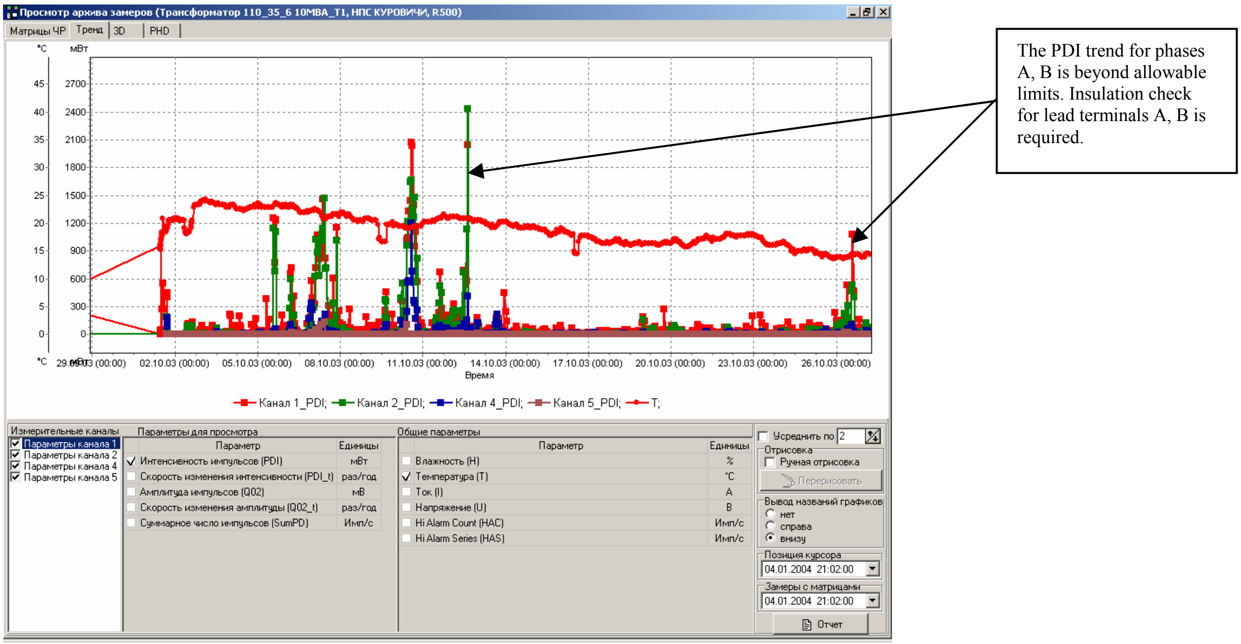


Fig. 3. Displaying Partial Discharge Intensity in Lead Terminals of 110 kV, 35 kVA Transformer of Petroleum-Transfer Station “Куровичи (Kurovichi)”

Просмотр архива замеров (Трансформатор 110_35_6 10МВА_Т1, НПС КУРОВИЧИ, R500) - Looking through the measurement archive (Transformer 110_35_6 10MBA_T1, Oil-Transfer Station, KUROVICHI, R500***)***.

Матрицы ЧР	PD matrices	Общие параметры	General parameters
Тренд	Trend	Влажность	Humidity
мВт	mW	Температура	Temperature
Канал	Channel	Ток	Current
Время	Time	Напряжение	Voltage
Измерительные каналы	Measuring channels	А	A
Параметры канала	Channel parameters	В	V
Параметры для просмотра	Parameters for viewing	Усреднить по	Average out by
Параметр	Parameter	Отрисовка	Drawing
Интенсивность импульсов	Partial discharge intensity (PDI)	Ручная отрисовка	Manual drawing
Скорость изменения интенсивности	PDI rate	Перерисовать	Redraw
Амплитуда импульсов	PD pulse magnitude	Вывод названий графиков	Graph name displaying
Скорость изменения амплитуды	PD magnitude rate	нет	No
Суммарное число импульсов	Pulse summary number	справа	Right
Единицы	Units	внизу	Down
раз/год	time / year	Позиция курсора	Cursor position
имп/с	pulse / s	Замеры с матрицами	Measurements with matrices
		Отчет	Report

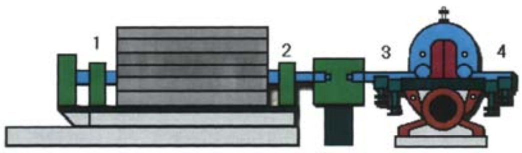
НПФ ДАТОС Лтд 29.11.2007 11:15:48

ВАТ Укртранснафта, філія МН Дружба

Отчет по диагностике за
12.11.2007 10:23:08
НПС "ЖУЛИН"
Магистральный насосный агрегат 2.3

Наработка агрегата от последнего ремонта (по состоянию на 29.11.2007 11:15:48) 6046.6 часов
Наработка (по состоянию на 29.11.2007 11:15:48) ЭД с начала эксплуатации 152146.1 час.
Наработка (по состоянию на 29.11.2007 11:15:48) ЭД после кап. ремонта 6046.1 час.
Наработка (по состоянию на 29.11.2007 11:15:48) Насос с начала эксплуатации 152146.1 час.
Наработка (по состоянию на 29.11.2007 11:15:48) Підш ковз ел.дв. 120146.1 час.
Наработка (по состоянию на 29.11.2007 11:15:48) Насос после КР 6046.1 час.
Наработка (по состоянию на 29.11.2007 11:15:48) Насос после ТО 4646.1 час.
Наработка (по состоянию на 29.11.2007 11:15:48) Вал 6046.1 час.
Наработка (по состоянию на 29.11.2007 11:15:48) Підш ковз насоса 83146.1 час.
Наработка (по состоянию на 29.11.2007 11:15:48) РУП 6046.1 час.
Наработка (по состоянию на 29.11.2007 11:15:48) Муфта пластинч. 6046.1 час.

Operating time of
rotary machine units



Величина виброскорости (СКЗ, мм/с) в диапазоне частот от 10 до 1000 Гц

Точка Напр.	Точка 1	Точка 2	Точка 3	Точка 4
В	1.7	3.9	1.1	1.0
П	4.0	3.5	3.2	2.2
О	-	6.1	-	2.5

Элемент	Дефект	Вероятность обнаружения	Степень развития дефекта	Рекомендации
Подшипник 1	Увеличение зазоров	60	0.44	Подшипник в тревожном состоянии
Подшипник 2	Увеличение зазоров	75	0.49	Подшипник в тревожном состоянии
точки 2,3	Расцентровка	80	0.53	Степень развития дефекта мала; дефект не требует устранения
точка 3	Кавитация	80	0.34	Степень развития дефекта мала; дефект не требует устранения
точка 4	Кавитация	80	0.21	Степень развития дефекта мала; дефект не требует устранения

The operation results of the
Integrated System
diagnostic processor

Fig. 4.

1

UKRTRANSNAFTA Public Stock Company, Branch Establishment of FRIENDSHIP International Pertroleum Pipeline

Diagnosis Report
as of 12.11.2007 10:23:48
ZHULIN Petroleum-Transfer Station
Pipe-Line Pump Unit 2.3

Operating time of rotary machine units

Operating time of the unit after the most recent repair (as of 29.11.2007 11:15:48) is 6046.6 hours
Operating time (as of 29.11.2007 11:15:48) of the electric motor after the commencement of operation is 152146.1 hours.
Operating time (as of 29.11.2007 11:15:48) of the electric motor after the major overhaul is 6046.1 hours.
Operating time (as of 29.11.2007 11:15:48) of the pump after the commencement of operation is 152146.1 hours.
Operating time (as of 29.11.2007 11:15:48) of the slider bearing of the electric motor is 120146.1 hours.
Operating time (as of 29.11.2007 11:15:48) of the pump after the major overhaul is 6046.1 hours.
Operating time (as of 29.11.2007 11:15:48) of the pump after maintenance is 4646.1 hours.
Operating time (as of 29.11.2007 11:15:48) of the shaft is 6046.1 hours.
Operating time (as of 29.11.2007 11:15:48) of the slider bearing of the pump is 83146.1 hours.
Operating time (as of 29.11.2007 11:15:48) of the РУП (angular contact ball bearing) is 6046.1 hours.
Operating time (as of 29.11.2007 11:15:48) of the plate clutche is 6046.1 hours.

Vibration Velocity (Root-Mean-Square Value, mm/s) within Frequency Band of 10 to 1,000 Hz

Tension Point	Point 1	Point 2	Point 3	Point 4
В	1.7	3.9	1.1	1.0
О	4.0	3.5	3.2	2.2
П	-	6.1	-	2.5

The operation results of the Integrated System diagnostic processor

Element	Defect	Detection Probability	Degree of Defect Progressing	Guidelines
Bearing 1	Increasing of gaps	60	0.44	The bearing is an in alarm condition
Bearing 2	Increasing of gaps	75	0.49	The bearing is in an alarm condition
Points 2, 3	Disalignment	80	0.53	The degree of defect progressing is low. It is not required to eliminate the defect
Point 3	Cavitation	80	0.34	The degree of defect progressing is low. It is not required to eliminate the defect
Point 4	Cavitation	80	0.21	The degree of defect progressing is low. It is not required to eliminate the defect

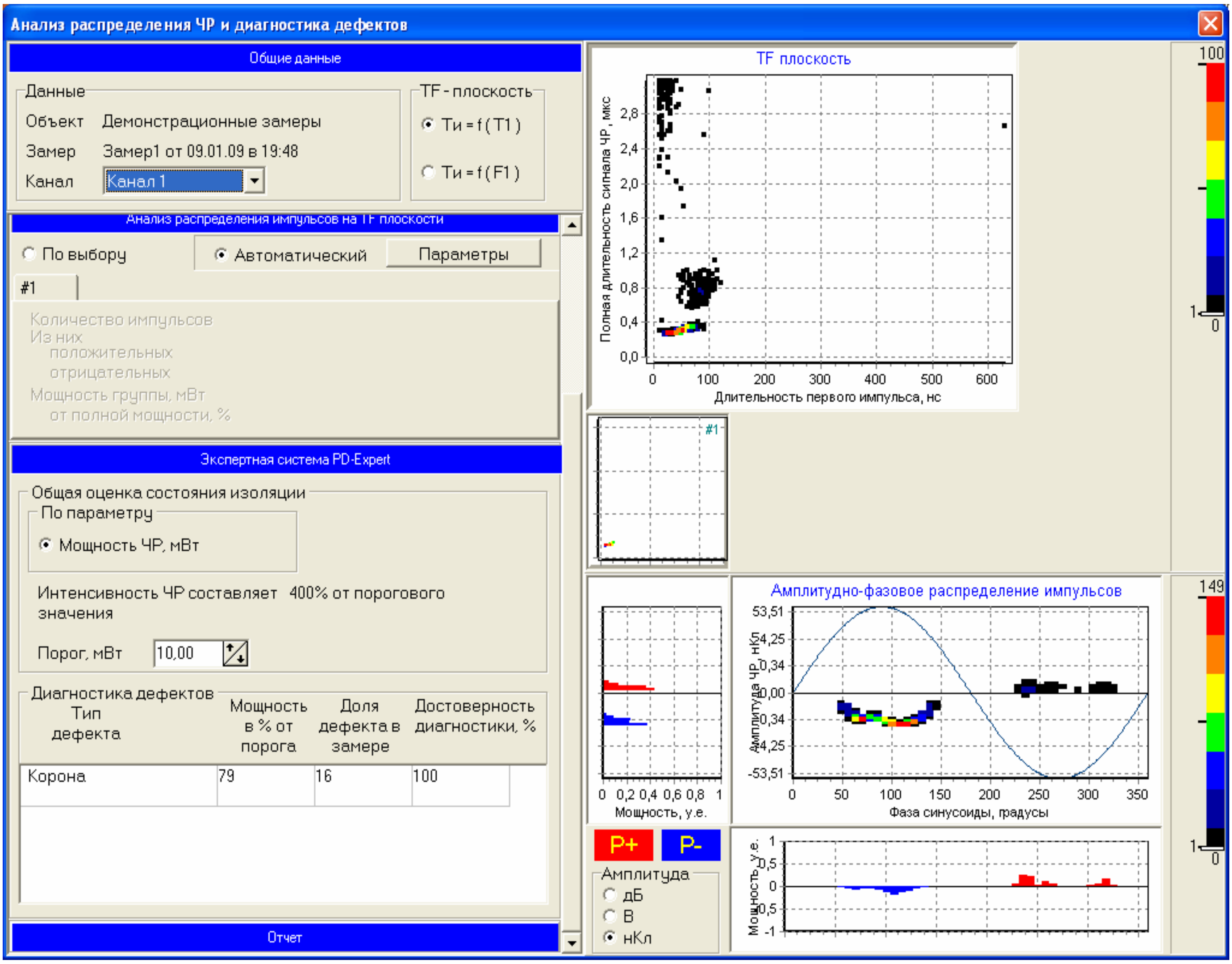


Fig. 5. Illustration of PD Analysis and Search for Defects in Insulation Performed by Diagnostic Processor

Анализ распределения ЧР и диагностика дефектов	Analysis of PD distribution and diagnosis of defects	Общая оценка состояния изоляции	General evaluation of insulation condition
Общие данные	General data	По параметру	By parameter
Данные	Data	Мощность ЧР, мВт	PD power, mW
Объект	Object	Интенсивность ЧР составляет 400 % от порогового значения	PDI is 400 % of the threshold
Демонстрационные замеры	Demonstration measurements	Порог, мВт	Threshold, mW
Замер	Measurement	Диагностика дефектов	Diagnosis of defects
Замер 1 от 09.01.09 в 19:48	Measurement 1 as of 09.01.09 at 19:48	Тип дефекта	Defect type
TF плоскость	TF plane	Мощность в % от	Power in % of the

		порога	threshold
Анализ распределения импульсов на TF плоскости	Pulse distribution on the TF plane	Доля дефекта в замере	Defect portion in the measurement
По выбору	At option	Достоверность диагностики, %	Diagnosis trustworthiness, %
Автоматический	Automatic	Корона	Corona
Параметры	Parameters	TF плоскость	TF plane
Количество импульсов	Number of pulses	Полная длительность сигнала ЧР, мкс	Total PD signal duration, μs
Из них	Of them	Длительность первого импульса, нс	Duration of the first pulse, ns
Положительных	Positive	Амплитудно-фазовое распределение импульсов	Amplitude-phase distribution of pulses
Отрицательных	Negative	Амплитуда ЧР, нКл	PD magnitude, nC
Мощность группы, мВт	Group power, mW	Фаза синусоиды, градусы	Sine curve phase
От полной мощности, %	Of total power, %	Мощность, у.е.	Power, conventional units
Экспертная система PD-Expert	PD-Expert system	Амплитуда, дБ, В, нКл	Magnitude, dB, V, nC

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