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ANALYSIS OF THE EXISTING AND DEVELOPMENT OF NEW SOFTWARE PACKAGES FOR PROCESSING AND INTERPRETING OF GEOPHYSICAL WELL LOGGING DATA

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АНАЛИЗ СУЩЕСТВУЮЩИХ И РАЗРАБОТКА НОВЫХ ПРОГРАММНЫХ КОМПЛЕКСОВ ОБРАБОТКИ И ИНТЕРПРЕТАЦИИ ИНФОРМАЦИИ О ГЕОФИЗИЧЕСКИХ ИССЛЕДОВАНИЯХ СКВАЖИН

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oil and gas geophysics, geophysical well survey methods, monitoring well technical condition, acoustic logging, waveform acoustic logging, well defectoscopy, acoustic cement bond logging, radiometric cement bond logging, profile logging, software, compression algorithms, software packages comparison, software architecture, software object model, software component model, wavelet transform.

At present there exists many packages for interpreting geophysical well logging data, permitting to solve geological tasks and monitor well technical condition. For well condition status evaluation a complex of geophysical methods is used, including acoustic, radioactive, electromagnetic and other methods.
This article makes a comparative analysis of possibilities of the existing well logging software packages for monitoring well technical condition. In the course of the studies we have in details analyzed both packages by other developers and own modular system for processing and interpreting geophysical well logging data («SONATA»), reviewing possibilities of the programs at all stages of data processing and interpreting: various data formats support, material quality evaluation according to industry standards, step-by-step processing support, preprocessing, signal parameters determination, calculation of physical mechanical properties and other parameters, processing data of various acoustic, radioactive, electromagnetic methods and profile logging. Advantages of «SONATA» system in comparison to the existing program complexes are demonstrated.
Internal arrangement of «SONATA» system and utility software packages accompanying the program package is analyzed in details. Major peculiarities of «SONATA» system software architecture are presented: object and component models reflecting internal arrangement of interpreting complex. From the companion programs in details are analyzed geophysical well logging data compression packages, their evolution and algorithms developed for compression.
Many years of experience of using geophysical well logging data processing and interpreting modular system «SONATA» by geophysical organizations in Russia and former USSR have demonstrated that the software complex is in demand with oilfield servicing organizations, permitting them to solve the complete range of tasks on monitoring well technical conditions, providing ergonomic interface and convenient set of tools for generation of resulting conclusions and documents.

Ключевые слова:
нефтегазовая геофизика, геофизические методы исследования скважин, контроль технического состояния скважин, акустический каротаж, волновой акустический каротаж, дефектоскопия скважин, акустическая цементометрия, радиометрическая цементометрия, профилеметрия, программное обеспечение, алгоритмы сжатия, сравнение программных комплексов, архитектура программного обеспечения, объектная модель программы, компонентная модель программы, вейвлет-преобразование.

В настоящее время существует множество пакетов интерпретации данных геофизических исследований скважин (ГИС), позволяющих решать геологические задачи и осуществлять контроль технического состояния скважин. Для оценки состояния скважин используют комплекс геофизических методов, включая акустические, радиоактивные, электромагнитные и др.
В статье выполнен сравнительный анализ возможностей существующих программных комплексов ГИС для контроля технического состояния скважин. Детально проанализированы как пакеты других разработчиков, так и собственная модульная система обработки и интерпретации данных геофизических исследований скважин («СОНАТА»). Рассмотрены возможности программ на всех этапах обработки и интерпретации: поддержка различных форматов данных, оценка качества материала в соответствии с отраслевыми стандартами, поддержка пошаговой обработки, предварительная обработка, определение параметров сигнала, расчет физико-механических свойств и других параметров, обработка данных различных акустических, радиоактивных, электромагнитных методов и профилеметрии. Показаны преимущества системы «СОНАТА» по сравнению с существующими программными комплексами.
Подробно проанализировано внутреннее устройство системы «СОНАТА» и служебных пакетов программ, сопровождающих указанный программный комплекс. Представлены важнейшие особенности программной архитектуры системы «СОНАТА»: объектная и компонентная модели, отображающие внутреннее устройство интерпретационного комплекса. Из сопутствующих программ детально проанализированы пакеты сжатия скважинных геофизических данных, их эволюция и разработанные для сжатия алгоритмы.
Многолетний опыт использования модульной системы обработки и интерпретации данных геофизических исследований скважин «СОНАТА» в геофизических организациях России и ближнего зарубежья показал, что программный комплекс является востребованным в нефтесервисных организациях, позволяя решать полный спектр задач контроля технического состояния скважин, предоставляя эргономичный интерфейс и удобный набор средств для формирования итоговых выводов и документов.

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Introduction

At present a variety of programs for geophysical well logging data interpretation [1–5] exists, permitting to solve geological tasks and monitor well technical condition. For evaluation of well condition a complex of methods is used [1, 4, 6–12], including acoustic, radioactive, electromagnetic and other methods.

In this respect it is important to perform comparative analysis of possibilities of the existing logging software packages designated for monitoring well technical condition. It is necessary to review program possibilities at all stages of processing and interpreting: various data formats support, material quality evaluation according to industry standards [13], step-by-step processing support, preprocessing [14], signal parameters determination [15, 16], calculation of physical mechanical properties and other parameters [6], processing data of various acoustic, radioactive, electromagnetic methods [17, 18] and profile logging.

Analysis of existing packages for geophysical well logging data processing and interpreting

Most widely for geophysical well logging data processing and interpreting following packages are used: «SONATA» [19, 20], «Praim», «Gintel», «Pangeya», «SIAL-GIS», «Kamerton», DV-Geo, Geophysics Office, Tigress, «GeoPoisk», Techlog («Schlumberger»), LogPWin «Neftegazgeofizika» LLC. From the named software means the most spread in the territory of the Russian Federation for tasks of evaluating well technical condition and waveform acoustic logging processing are the following packages: «Praim», «Kamerton», «GeoPoisk», Techlog, LogPWin, «SONATA» [21–25]. LogPWin has different modules for processing specialized geophysical methods, but is bound to hardware made only by «Neftegazgeofizika» LLC. Techlog platform, due to variety of different modules, may be used for processing practically any logging data, but because of high price it is used in the RF only in small quantities by large oil and service companies, and it also has limitations on support of a number of domestic hardware complexes.

In table 1 given below comparative characteristics of each package for processing and interpreting logging data for purposes of technical condition evaluation and waveform acoustic logging data processing are showed.

From table 1 it is seen that among the presented software packages «SONATA» system possesses to the fullest extent all necessary functionality in the field of technical condition evaluation and waveform acoustic logging data processing. Closest its competitor in terms of functionality is Techlog system («Schlumberger»), but it is not Russian, and also, as it was stated above, poorly supports domestic hardware and is also expensive. Packages GeoPoisk» and «Praim» have enough wide functionality, but they are used mainly for processing and interpreting standard logging complexes on open bore or during reservoir management. «Kamerton» software package has developed waveform acoustic logging data processing and interpreting procedures, bur recently its evolution stopped.

Development of geophysical well logging data processing and interpreting «SONATA» modular system

«SONATA» software package is an evolution of computer software for wave signal processing «GIS-Akustika» и «GIS-AKTz» [26], which were intended for evaluation of well cementing quality according to acoustic logging data.

Main purpose of the software package is effective processing and interpreting of data registered by various geophysical hardware, using a variety of geophysical methods and procedures, not limited to acoustic logging only [27]. During development of «SONATA» software main attention was given to tasks of complex evaluation of well technical condition and data processing by different methods [22–25, 28, 29].

Creation of such software tools package supposes performance of works on wide range of issues related to data storage formats standardization, development of informational model and its functionality [19], including selection of data processing and interpreting methods, interface planning with software implementation, testing and introduction [2].

This variety of works was performed by «Predpriyatie "FKhS-PNG"» LLC, directed by author of the article, whose input to development of «SONATA» software package was building topical area informational model and determination of potential users conceptual requirements.

Table 1

Comparative characteristics of software packages

Characteristics	«Praim»	«Geopoisk»	LogPWin	«Kamerton»	Techlog	«SONATA»
Data format support (0–5 / 6–10 / 11–20)	6–10	11–20	0–5	0–5	6–10	11–20
Quality evaluation per industry standards	yes	partially	no	partially	partially	yes
Wave signal preprocessing	no	partially	partially	yes	yes	yes
Traveltime parameters determination	yes	yes	yes	yes	yes	yes
Dynamic parameters determination	partially	partially	yes	yes	partially	yes
Spectral parameter determination	no	no	partially	no	partially	yes
Azimuthal anisotropy determination	no	partially	partially	yes	yes	yes
Wellbore geometry consideration	no	no	partially	yes	yes	yes
Calculation of physical mechanical properties	partially	partially	partially	partially	yes	yes
Inflow coefficient evaluation	no	no	no	no	no	yes
Step-by-step processing wizards	yes	no	no	no	yes	yes
Acoustic cement bond logging	yes	yes	yes	yes	yes	yes
Acoustic cement bond logging. Well conditions consideration *	partially	no	no	no	yes	yes
Sector acoustic cement bond logging	no	no	no	no	yes	yes
Processing well gamma defectoscope-thickness tool	yes	yes	partially	no	no	yes
Well gamma defectoscope-thickness tool. Well conditions consideration **	no	no	no	no	no	yes
Magnetic pulse defectoscopy processing	yes	no	no	no	no	yes
Multi-finder profiling tool processing	yes	yes	partially		yes	yes
Acoustic profile logging	no	no	yes	no	no	yes
Report generation	yes		partially	partially	yes	yes

Note: (purple) – no; (green) – yes; (yellow) – partially; * – type of section, cement properties, well design; ** – multistring design, fluid level, eccentricity, etc.

Conceptual model development was based on analysis of data processing tasks being solved by different geophysical enterprises. Building topical area informational model supposed recognition of entities, their attributes and identification of connections between entities. Modeling and building software informational model was performed using IBM Rational Software Architect tool and UML language (Unified Modeling Language).

Advantage of using UML for informational model description is that UML is a unified graphical description language for object modeling in software development, business processes modeling, system engineering and reflecting organizational structures, which is equally understood both by topical area specialists and software developers.

That is why in the first instance comprehensive topical area analysis was performed, main conceptual requirements to the package being developed were described, system object and component models were built.

Fig. 1 shows developed system object model, which permitted to describe, within same information field, objects having diverse internal structure and composition of elements, establish complex multilevel relations between informational objects, separate both general and individual object properties.

As distinguished from object model, which reviews relations between objects, component model is an abstract presentation of system being developed, in which elements are actual components providing for implementation of system functional requirements.

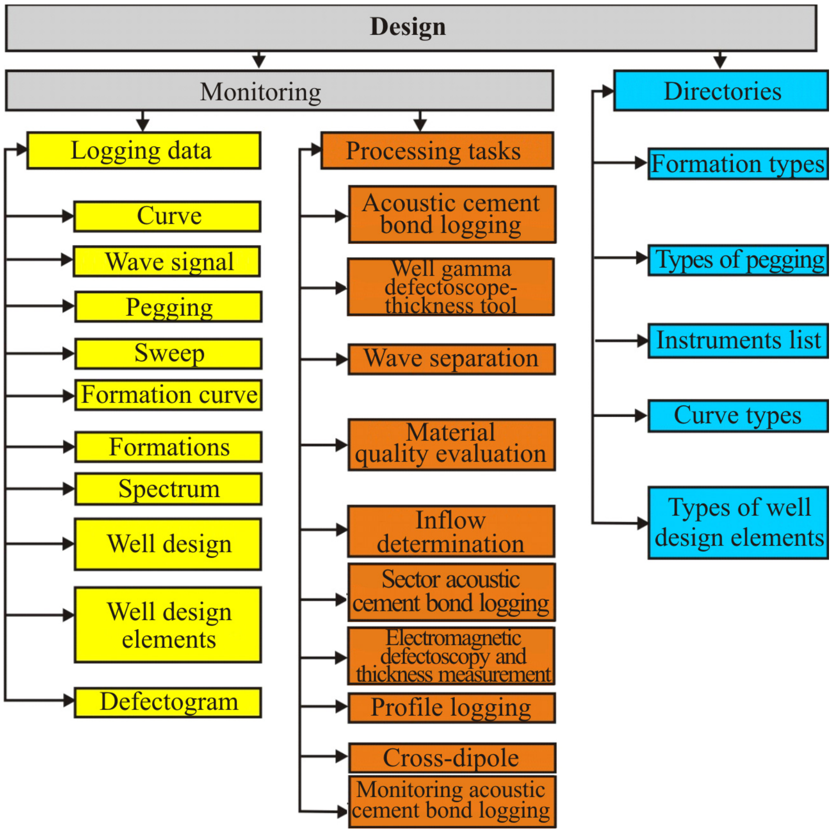

Fig. 1. Object model of «SONATA» system

For the same system many component models exist, depending on design concepts using component approach. Let us study summary model presentation level, using component functions and cluster of contracts (interfaces) between them.

Let *M*[*I*] – variety of interfaces related to determination of components functions. To each *I* it is possible to assign interface *In*, describing interface as client-server interaction with corresponding methods and data structures. Accordingly to this, to each interface it is possible to assign pair *In* and *Out*, which let be called determining presentation *In* and implementing presentation *Out* (which corresponds to input and output interfaces). *In* determines conditions and purpose of interface on client side, and *Out* sets aspect of interface implementation on server side.

After all *In* and *Out* are determined, they could be grouped into various combinations for elements *C*. Let us see an arbitrary cluster In_j, Out_j. It includes simultaneously determining and implementing presentations for the same interface.

Each obtained cluster *C* and *I* is included into component model and is a component template. Actually each template contains a certain variety of determining and implementing presentations of interfaces. According to these presentations actual software components templates and interfaces are further compared.

Component system model looks like

$$M_{кс} = (CL_m(Lm_1, ..., Lm_n), \\ P(_1, ..., P_m), CL_n(In_1, ..., In_k), D_i,$$

where CL_m – components from variety of implementations in different languages *L*; $P(P_1, ..., P_m)$ – variety of predicates corresponding to processes of assembling or configuring software tool on basis of implementations of components CL_m and interfaces *In*; CL_n – variety of components interfaces; D_i – variety of data.

Component system model $M_{кс}$ consists of variety of functions (objects), implementations, predicates, interfaces and data.

System integrity condition is the existence for each component C_x from *C*, having initial interface *In*, of component C_z with corresponding input interface CIn_z, and contract $Cont_z$, included in variety *C*.

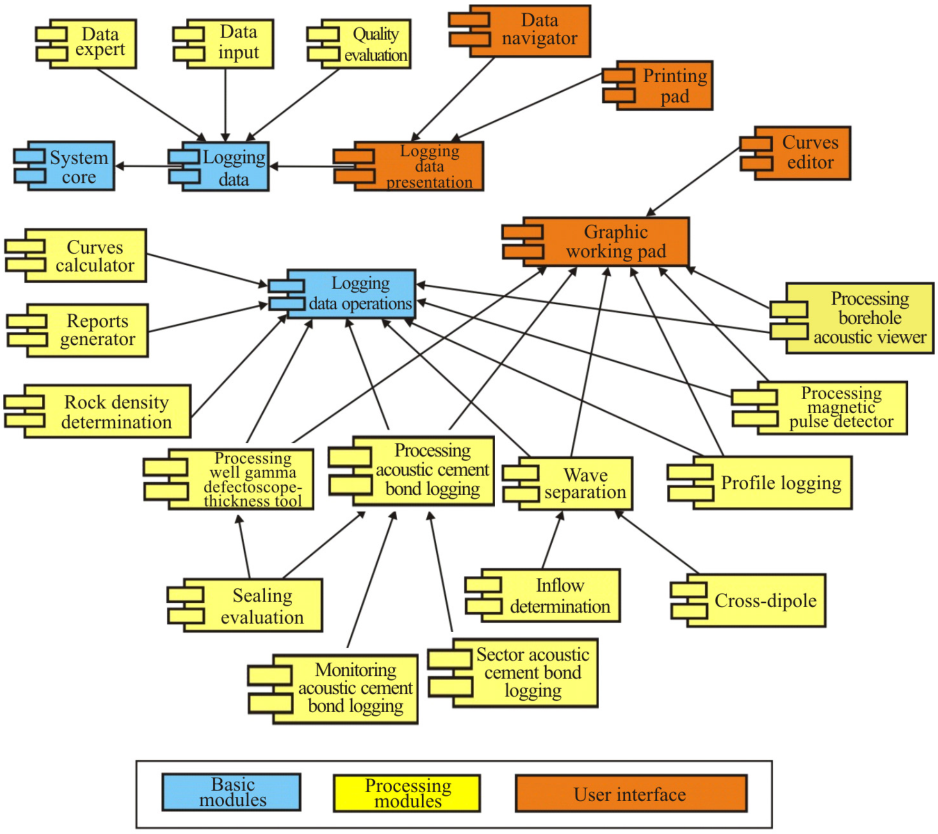

Fig. 2. SONATA system component model.

Build process $M_{кс}$ includes creation of component environment, detection of initial components and certain variety of interfaces according to component system functional requirements. Essence of system modeling – to present model $M_{кс}$ so that for each system element there exists a component from C, or it may be obtained from C' by a finite number of valid component algebra operations.

Fig. 2 shows developed component model of «SONATA» software package.

Developed «SONATA» software package includes the following main modules [30]: acoustic cement bond logging data processing and interpreting; well gamma defectoscope-thickness tool data processing and interpreting; joint interpretation of data of acoustic cement bond logging and well gamma defectoscope-thickness tool (determination of borehole annulus sealing); processing and interpreting open bore waveform acoustic logging, including modules for wave separation, obtaining traveltime, dynamic and spectrum wave characteristics, calculation of rock physical mechanical properties, determination inflow intervals according to wave signal full energy [9]; rock density determination according to complex of neutron and gamma logging; processing borehole acoustic viewer data [9, 31]; processing magnet pulse defectoscopy data [29, 32]; processing sector acoustics data [23, 33]; processing cross-dipole acoustic logging [24, 34].

Main program possibilities, except above stated: data input from majority of known geophysical formats (LIS, LAS, etc.), data exports to different formats; field data quality check, including wave signal quality check; data preprocessing, correction and preparation; editing depths and data association by depth; interpreting acoustic cement bond logging and gamma-gamma cement bond logging data, their complex interpretation; processing acoustic noise logging data; borehole profile logging [35, 36]; generation of conclusion, according to results of complex interpretation, including detailed interval well performance, technical conditions, design elements location, various statistics, including that in detailed study intervals.

Workability of software usage is increased because of presence of processing wizards helping to obtain necessary results in step-by-step mode. Possibility to describe input templates permits to automate input of additional information on well and conclusion generation.

Consequently, developed «SONATA» software package is an effective tool for well technical condition evaluation, including complex processing and interpreting technology for a wide range of geophysical methods. Usage of single software package for evaluation of well technical condition, including universal processing of data obtained by majority of geophysical instruments, both of Russian and foreign manufacture, permitted to substantially reduce time necessary to obtain complex conclusion, meanwhile usage of data obtained at different stages of well construction, starting from studies of open bore, casing and up to studies of technical condition of production string and tubing string, permitted to significantly increase certainty and informativeness of well condition monitoring, especially in multi-string intervals and difficult geology-technical conditions.

Creation of utility software packages intended for logging materials compression and storage

One of peculiarities of acoustic logging is considerably greater data volume comparing to analogue curves. Accordingly, requirements to data storage and exchange devices increase, as to processing and interpretation software. Initial data compression without losses using standard archiving programs may in average provide compression degree of 1,5–3,0 times, which is often not enough for data transfer. Waveform acoustic logging data compression may be used for: transmitting field waveform acoustic logging material over low speed digital communication channels from remote field crews to interpretation services located at base; archiving source and processed material; data exchange between subdivisions of organizations.

Program «Szhatie VC» [37] become one of first steps on unification of formats for waveform acoustic logging data storage and presentation. Requirements to waveform acoustic logging data compression algorithm: providing for operative compressed data delivery for interpretation; error of parameters extracted from wave signal before and after compression, is within the prescribed values; performing lossy data compression after recording the whole material; archiving compression with minimal permitted distortions for the whole signal. These requirements were implemented in program «Szhatie VC», providing for: support of majority wave signal recording formats; compatibility with «SONATA» software in data formats; setting permitted signal distortion value in different areas, which permits to achieve optimal ratio «minimal useful signal distortions / maximal compression degree»; possibility of visual signal comparison before and after compression; preliminary evaluation of signal compression ratio; deletion of non-informative signal parts before primary arrivals and in signal end; packing logging curves and processed data obtained by «SONATA» software together with wave signal.

Further evolution of program was limited by its purpose to compress only waveform acoustic logging signals. Also increase of data packing / unpacking speed and reduction of errors at poor wave signal quality and low amplitude distortions at certain compression parameter settings were desirable. All that determined need of significant changes and promoted creation of new program «Szhatie GIS» [28, 38]. For operative large volume logging data transmission it is necessary to use algorithms permitting, with minimal errors in informative source data parts, to provide for compression degree by an order higher than that of standard no-lossy compression algorithms. Source data may be split into various informative blocks, and separate error / compression degree may be set for each block. This permits to compress less informative parts with greater degree of compression, and vice versa, leave more informative parts with less distortions. Compression degree within permitted error of parameters being calculated for different methods, depending on geological-geophysical tasks being solved, may considerably vary – from several times to tens and hundreds of times.

As basis for compression method in program «Szhatie GIS» principle of data wavelet transform is used [39, 40].

Essence of the method is the following.

Source data are real number matrix $F_{mn}F_{mn}$ (geophysical data) and compression coefficient $K \in (0; 1)$.

Compression algorithm is the following:

• Depending on geophysical data type source data F_{mn} may be subjected to preliminary transformation (without accuracy loss) $Y(F_{mn})$. Obligatory condition for selection of transformation

Y is presence of reverse transformation Y', such, that $F_{mn} = Y'(Y(F_{mn}F_{mn}))$.

• Wavelet transform using two-dimensional wavelet is applied to two-dimensional data $F_{mn}F_{mn}$. Wavelet selection is made automatically depending on source data. Fitting criterion is minimization of functionality $\Psi\left(\frac{\Delta}{K}\right)$, where Δ – relative error of calculated parameters as result of compression.

Let there be source data matrix with size $m \times n$. Single-dimensional wavelet transform is applied to each matrix line. For each line we obtain matrix

$$\begin{vmatrix} d_1^1 & d_2^1 & d_3^1 & d_4^1 & \dots & d_{N/2}^1 \\ d_1^2 & d_2^2 & d_3^2 & \dots & d_{N/4}^2 & \\ & & \dots & & & \\ d_1^M & d_2^M & \dots & d_K^M & & \\ s_1^M & s_2^M & \dots & s_K^M & & \end{vmatrix}.$$

This matrix is transformed into array so that averaging factors appear first

$$s_1^M\ s_2^M \dots s_K^M,\ d_1^M\ d_2^M \dots d_K^M,\ \dots,$$
$$d_1^2\ d_2^2\ d_3^2 \dots d_{N/4}^2,\ d_1^1\ d_2^1\ d_3^1\ d_4^1 \dots d_{N/2}^1.$$

From the arrays received new matrix is made with size $m \times n$. Similar actions are applied to each column in the new matrix.

• Elimination algorithm is applied to the obtained wavelet transform coefficients, i.e. all coefficient are zeroed except N of the largest, where $N = m \times n(1 - K)$.

• Wavelet transform coefficients are presented in form of single-dimensional real array.

• The obtained real number array is subjected to selected quantizing type, resulting in byte array.

• The obtained byte array is compressed using any standard no-lossy compression algorithm.

Signal restoration is made in opposite order, using reverse single-dimensional wavelet transform.

This developed procedure permits to adapt data compression practically for any large multidimensional data of field geophysical methods on condition that method of informative parameters extraction from source data is known.

Main characteristics of «Szhatie GIS» software package: loading logging data from various field formats; viewing loaded data in graphic form; field material quality evaluation with issuance of a conclusion; source data preprocessing and preparation; generating and filling in operator form; data export to different data exchange formats; quick field material compression and unpacking; maximal compression degree within permitted error of geophysical methods; compression and unpacking large volume logging data (hundreds of megabytes); compressing data of acoustic logging, magnetic pulse defectoscopy, well profile logging, etc. In total 211 «Szhatie GIS» workplaces are installed in different geophysical organizations.

Analysis of source data compression was performed for different logging methods (acoustic cement bond logging, wide band waveform acoustic logging, acoustic profile logging, magnet pulse defectoscopy, etc.), evaluation of informative parameters error was performed for each method before and after compression. It was shown that at permitted relative error compression degree for different geophysical methods may vary from 10 to 100 times. Average compression degree for complex of geophysical methods on evaluation of string technical condition is 20 times.

Fig. 3 shows that maximal compression degree is obtained for instruments for sector acoustic cement bond logging (MAK-SK) and magnet pulse defectoscopy (MID-K).

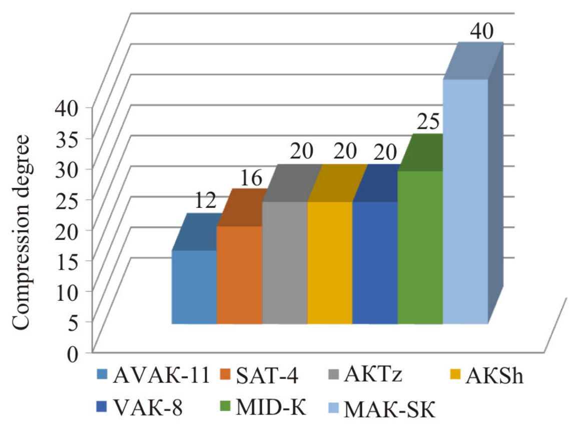

Fig. 3. Approximate compression degree for different methods and instruments within permitted error of calculated parameters

Consequently, developed method and «Szhatie GIS» program permit to solve problem of operative source large volume geophysical data transfer from well to interpretation centers.

At present over 50 different enterprises in the RF, Kazakhstan, Turkmenia, Vietnam, Serbia use the developed software packages «SONATA» and «Szhatie GIS» in production environment.

Conclusions

Analysis of the existing software packages revealed that their majority have these or that drawbacks, related either to long history of software evolution, when new tools do not correspond to old architecture, or with narrow specialization, when not all well methods are used.

Developed «SONATA» software package is an effective tool for evaluation of well technical condition and waveform acoustic logging data processing, including complex processing and interpreting technology for wide range of geophysical methods.

Many years of experience of using geophysical well logging data processing and interpreting modular system «SONATA» by geophysical organizations in Russia have demonstrated that the system is in demand with oilfield servicing organizations, permitting them to solve the complete range of tasks on monitoring well technical conditions, providing ergonomic interface and convenient set of tools for generation of resulting conclusions and documents.

The developed method and software for multidimensional logging data compression permit to effectively solve problem of large volume geophysical data preparation and delivery from remote field crews to interpretation centers over slow communication channels, which in turn helps to solve a pressing need of operative complex logging conclusion delivery to logging customer.

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