Surveying drill holes

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Received: December 16, 2008 **Accepted:** February 17, 2009

Abstract: The determining bore hole course is very important in drilling, and even more so in geologically complex, small oil and gas deposits, and high angle/ horizontal wells in which bottom hole location becomes necessary for successful drilling. Due to the high costs of drilling, rough drilling conditions and demands in a trajectory well control the use of modern technology, and can provide more data for the driller about the state of the borehole, the formation properties and the drill string in real time. This is provided by measuring while drilling (MWD) toll in drill string above the bit. These geological and engineering measurements are transmitted via mud pulses through the mud and to the surfacing operators' console.

Key words: drilling, measuring, trajectory, well, drill string.

Introduction

A driller's ability to optimize drilling performance increased with knowledge conditions on hole bottom in real time. MWD systems achieved great contribution to this, providing real time data, increasing safety and enhancing the financial aspect of drilling.

The most significant advantage of MWD technology is that it provides down hole measurements and their interpretations in real time. Furthermore these measurements are made before any substantial damage to the formation arises from invasion. As down hole measurements such as weight on bit, torque and temperature have never been available before, these capabilities result in better, faster drilling operations.

Highly deviated holes producing difficulties in logging operations and often only MWD tools can obtain formation properties.

Measured values from downward borehole are:

- Direction related data, inclination, and azimuth and tool face angle.
- State of the borehole, hydrostatic pressure, formation pressure, temperature.
- Drilling parameters, rotating speed, weight on bit, torque and condition of

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the bit.
- Formation properties, density, formation resistance, natural radioactivity and type of contents in the formation.

The impact that the MWD has on the safety of drilling is most significant. In addition to making provisions of the reliable detection of the pressure in formations by using the resistivity measurement method, the MWD measurement may also be used for the detection of the initial operating problems such as differential sticking. The use of the MWD affects the efficiency of drilling in several ways. Faster testing of the direction of the well enables more time for drilling, and more frequent measuring reduces the risk to turn away from the course (Vukelič, 2004).

At some wells with large angle of deflection, measuring of characteristics formation can even be the only measurement that can be obtained.

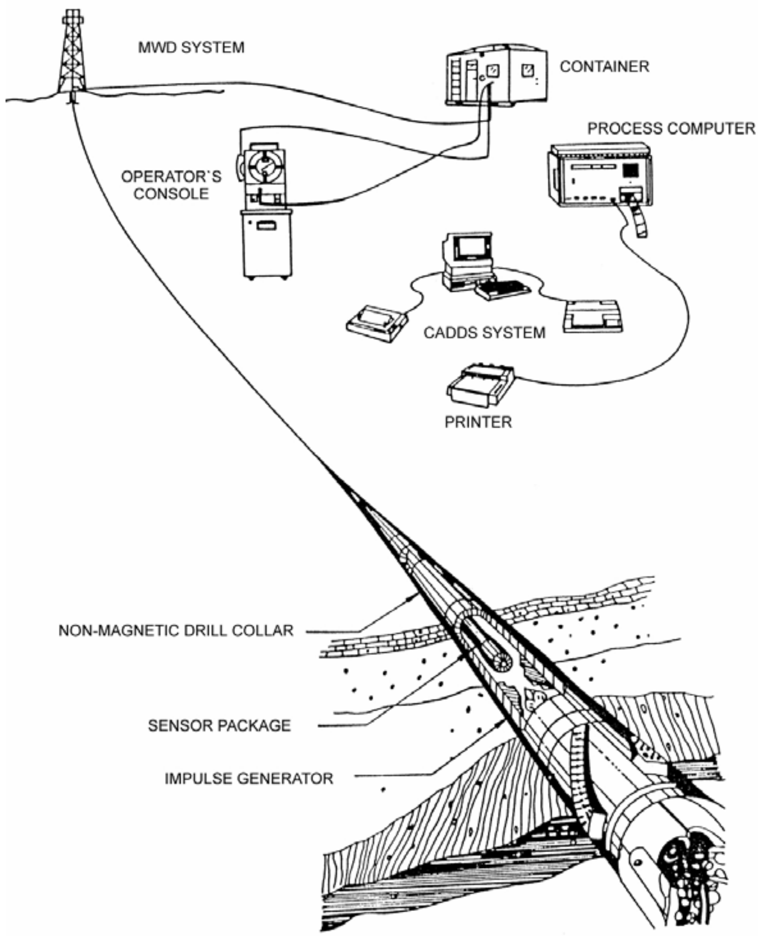

Figure 1. Measuring while drilling

Design of the MWD measuring systems

The MWD down hole tool consist of three main parts: measuring instruments with sensors, transmission element and surface equipment for receiving and manipulating the down hole data.

Measuring instrument in the drill string

The measuring instrument is located in the drill string, inside a special non-magnetic drill collar, close above the bit and/or the down hole motor and consist of the parts:

- Sensor or measured value receiver,
- Measured value processor which control system and codes the values and »telemeters« them to the surface by means of a transmission medium,
- Energy part, which provide power for the system from the batteries (lithium) or turbine generator driven by mud.

Surface equipment

In general, the surface recording equipment consists of device, which receives signals from the transmitter and converts them into electric pulses, and the decoder which provides representation of the measured values. Peripherals devices - such as digital computer, terminal, plotter and line printer - are usually connected to the system, ensuring analysing and storage of measured values.

The signal transmission systems

Depending on the type of a transmission medium and/or method used for transmission of data up to the surface, it is possible to classify the MWD systems in a clear and logical way. In most cases, they consist of electromagnetic wave system and the pulsating drilling fluid system. The type of the basic transmission is also crucial for the duration of transmission and/or frequency of data as well as for the quality of the obtained measured values. This is generally the result of the fact that the noise encountered in the transmission channel may reduce the efficiency of the transmission, sometimes resulting in the data interruption.

The electromagnetic transmission system

The electromagnetic system for the transmission of the obtained data up to the surface emits electromagnetic waves through the surrounding formations or through drilling tools. Due to the large transmission losses, it is possible to transmit only small frequency signals, so that it is very difficult to filter them. Electromagnetic waves tend to disappear in the formations with the resistance smaller than 1 Ω/m. The current commercial electromagnetic systems are suitable only for the land operations where the resistance is larger than 1 Ω/m and if the formation is not too deep.

The impulse transmission system by pulsation of the drilling mud

Two primary means of transmitting data, trough a fluid column inside drill pipes, to the surface exist:

- Pulse telemetry, encodes data in binary format and sends it to the surface by positive or negative pressure pulses generated by means of valve in the fluid;
- Continuous-wave telemetry employs

rotating device that generates a fixed frequency signal which sends binary information encoded on pressure wave to the surface.

The description of the signal transmission by drilling mud pulsation

During the pulsation process, the drilling mud pressure within drill collars near bit alters due to the effect of valves, so that the pressure drop or build-up of pressure occurs. Those impulses enable the signals transmission, because the impulses, made at the bottom, are spreading within the column of drilling mud at the speed of the sound, 1200 to 1500 m/s, all the way to the surface. This pulsation of pressure represents, in digital form, a coded group of analogously measured data. The speed of data transmission is from 1 to 3 bits per second (limited by pulsation valves and by the speed at which the valve actuation system is being shut down).

The positive pulse system

It represents the pulsation process, which causes the build-up of pressure within the drilling mud column by activating valve by means of the hydraulic system, which is controlled electronically.

- It enables every value of the pressure within practical limits and the pulsation can easily be detected.
- There is no direct communication between the inner space and annular.
- Currently, with the existing technique, higher rate of transmission is possible.

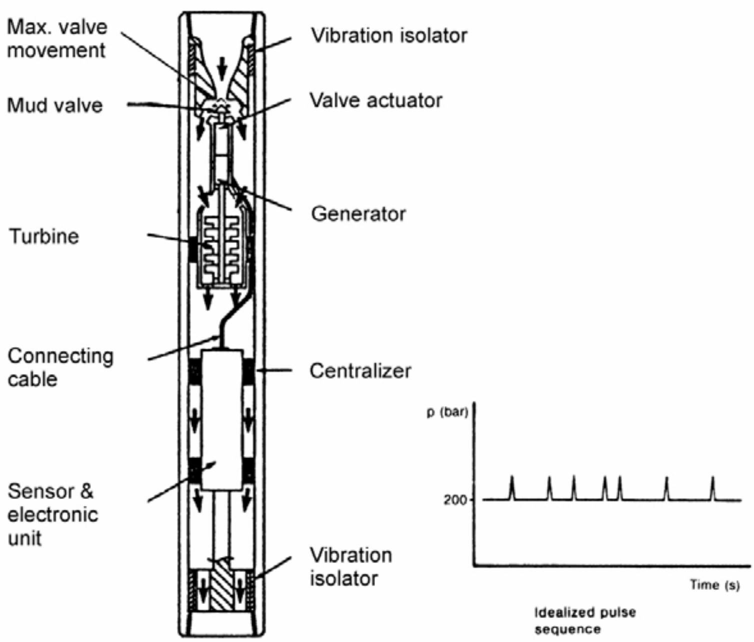

Figure 2. Positive pulse system

The negative pulse system

The principle of negative pulsation is based on the use of differential pressure, which exists inside and outside drill collars. The valve allows the discharge of drilling mud from the interior into the annular in a short time, and thus pressure drop noted on the surface occurs. The negative pulse system may cause permanent communication between the interior and the annular if the valve fails while closing.

- The pressure drop is possible up to approximately 10–15 % of the drilling mud pressure with complicated recognition of pulses.
- During the pulsation process, 5–20 % of drilling mud passes through the opening on the instrument into the annular.
- By using the existing technology, lower transmission rate is achieved than by using the positive system.

There is also another coding system in use, where the value of data is displayed by means of the interval between two pulses. The advantage of this system is higher speed for processing smaller value data.

Each pulse system is susceptible to noise made by drilling mud pump, and the filtration is made more difficult due to the wide range of frequencies contained in pulses. The drive system differs, and depending on the type of the valve used, it can be direct or with hydraulic servo valves.

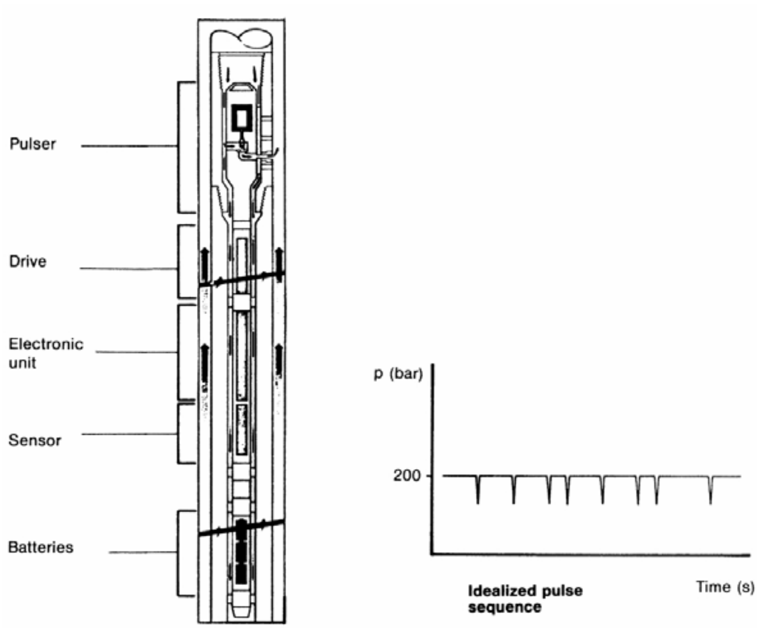

Figure 3. Negative pulse system

The continuous wave system
The drilling mud impulse generating system, the so called continuous wave system, uses the vortex pulsation valve, which, through fluid damping, produces the signal of pressure traveling through fluid within drilling pipes up to the surface at the speed of sound.

The most often wave frequency is 12 Hz and the alteration of phase is used more often than the frequency modulation.

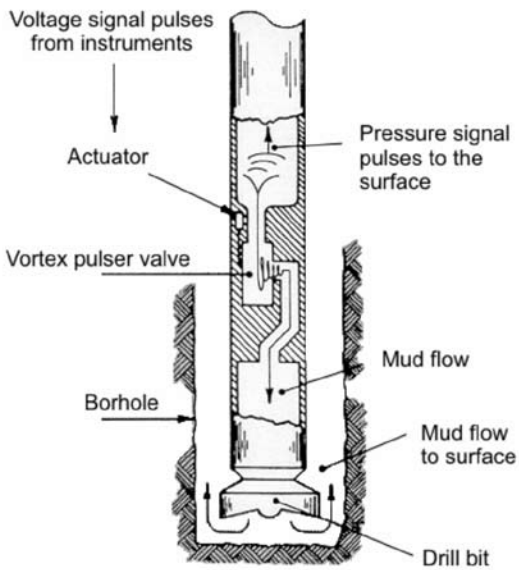

Figure 4. Continuous wave system

The pulsation transmission rate
The rate and weakening of drilling mud pulses depends on the drilling mud density, compressibility, as well as on the characteristics of drilling rods. It varies from 1500 m/s for light drilling mud to 1200 m/s for heavy drilling mud based on water. The speed within the drilling mud based on oil shall vary from 1200 m/s for light drilling mud to 1000 m/s for heavy drilling mud. Pressure impulse damping becomes increasingly intensive with the depth and compressibility of drilling mud. Even more expressed pressure reduction was observed at oil based drilling mud, which is mainly used at deep wells.

Reliability of the system

As the MWD systems are comprised of sensors, power supply sources, and pulsating unit and detecting system on the surface, it is probable that the system might fail.

In addition, the pulsating system contains elements with moving parts, so therefore is generally to expect larger tendency toward failing than with other components. Failing of MWD instruments results in premature pulling out of tools, which extends working time of the rig and directly affects the cost increase.

In the past, MWD tools were criticized because of their unreliability and poor durability. Today, the reliability is increased and the majority of producers guarantee more than 250 working hours between malfunctions.

By applying measurements of tool vibrations at the bottom, reliability of the MWD systems is improved and the lifetime of the bit and drilling tools is increased. Working energy of the probe is provided with batteries (lithium batteries – whereby it is necessary to provide approximately 200 working hours) or with generators. Turbine driven generator systems allow higher temperature than the systems with batteries.

All elements of the system are usually foreseen for the following conditions:

Temperature:	up to 150°C
Pressure:	up to 1500 bar
Shock:	up to 1000 G
Vibration:	up to 40 G

Large values of the resistance to impact and vibrations do not arise only from the conditions in the well during drilling; they are also necessary for the manipulation during transport and assembling. The majority of systems is susceptible to foreign objects in drilling mud (lost circulation material), so that it is necessary to put protective sieves at the inlet of the instrument.

The accuracy of the measurement is for the following:

Azimuth	± 1,5 º
Inclination	± 0,1 º
Face angle	± 1,5 º

THE APPLICATION OF MWD SYSTEMS

In general, the system consists of adequate sensors for analog or digital recording of the desired measured values, which can be divided into four groups of basic data:

Directing and guiding of drilling tools
- Tool face orientation
- Azimuth
- Inclination

Safety factors – conditions at the bottom of the well
- Hydrostatic pressure
- Mud flow
- Temperature

The optimization of drilling – drilling parameters
- Weight on bit
- Torque
- Rotating speed

Formation characteristics – geological correlation
- Natural radioactivity
- Formation resistivity
- Density
- Porosity

Directing and guiding of drilling tools

The first commercial application of MWD systems was for the directed drilling. The MWD testing lasts for 32 seconds compared with approximately one hour for the conventional measurement (*single-shot*). This leads to time savings and significant reduction of risks against the sticking of tools. Measurements made more often, which are enabled with MWD systems, allow better control of the direction and inclination during drilling. With modern accelerometers and magnetometers, complete data for inclination, orientation of the tool face and azimuth, including the magnetic correction are available. The inclination can be calculated with the equation (1). Gravitational angle of the tool face is the angle between vertical plane, which contains the well axis and planes of the mud motor, i.e. well axes. The term tool face refers only to drilling with mud motor. In case of housing with bent sub, lower part of the housing is to be considered as the tool face. Figure 5 shows the orientation of the tool face.

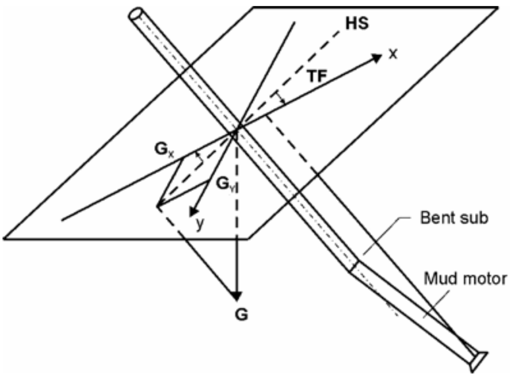

Figure 5. Planes defining the tool face angle

The angle TF is to be calculated with the following equation:

$$TF = \arctan\left(-\frac{G_y}{G_x}\right) \quad (1)$$

Where:
G_x = acceleration of gravity connected with the engine or the bit face in a plane normal to the axis of the well;
G_y = a normal to G_x in the same plane.
If $TF > 0$, well turns right, if $TF = 0$, well goes straight and if $TF < 0$, the well turns left. The angle TF is not defined if the inclination is zero. The drilling stage, in which the deflection begins, is called "*kickoff*". It is achieved by using bent sub and down hole motor to orient the tool face toward the angle of vertical plane, in which is the sub or the motor housing located in relation to the north.

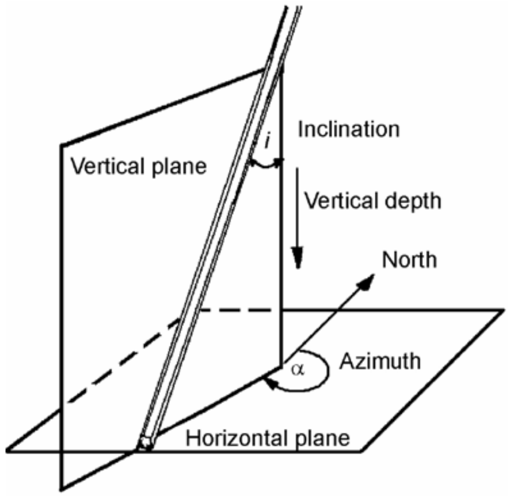

Figure 6. Planes defining the azimuth angle

The azimuth (α) is the angle between the direction of the north and the direction of the well in horizontal plane in clockwise direction (Figure 6).

The MWD sensors are positioned in the non-magnetic part of drill collars; however, magnetic pipes, which are distant, nevertheless have the impact by making perturbation in the direction of the well axis. This causes the error in measurement, which must be corrected. Those perturbations may arise from the points within the non-magnetic drill collars, where magnetism developed or due to the external factors such as the existence of casing in the vicinity.

With MWD system, an expert for directional drilling is able to determine the point of deflection precisely and to control operations for the correction of direction during process of reaching the geological aim.

Safety factors – conditions at the bottom of the well

The detection of high pressure and the appropriate maintenance of primary hydrostatic control of formation fluids is the most important safety problem affecting the drilling operations. Many methods for the detection and prediction of pore pressure are used, and the most frequently used is the method by which the resistance trends to predict overpressure zones and its comparison with the tendency of the pressure gradient determined in this area. By using values of pore pressure resulting from the MWD measurement in real time, the appropriate density of drilling mud can be chosen in order to maintain hydrostatic control and therefore to reduce the risk of kick. The indirect benefit of the use of MWD for determination of pore pressure is also the fact that drilling mud of minimum density can be used for appropriate pressure control, due to which the risk of losing the circulation is reduced and the drilling speed is increased.

The optimization of drilling – drilling parameters

The weight on bit at the bottom and torsion are significantly different from the surface measuring. The difference is especially characteristic at wells with deflection or while using stabilizer in the drilling tools column near bit. The difference between weight measured on the surface and the weight measured with MWD sensors may be used to determine the transfer of the efficiency ratio. The effectiveness depends on many factors such as well inclination, type of formation, drilling mud, lubricant used in circulation system etc. Sensors for measurement of weight at the bottom are also used to measure torsion on the bit during drilling. Sudden changes of torsion at the bottom signal the change of bit weight, types of formation or blocked bit cone. By using data from the surface and by using weight on bit at the bottom and torsion at the bottom for early detection of friction at the bottom in real time, a driller can take preventive action to avoid stuck pipe, to optimize bit performances and to avoid unnecessary trip with the tool.

Formation characteristics – geological correlation

Values obtained by MWD measurements and by conventional wire line logging measurements do not have to be identical (sensors do not measure absolutely the same condition of the layer); however, general compatibility is quite good and enough to permit the use of MWD chart for geological correlations and in some cases also quantitative calculations for evaluation of the formation. The advantage of MWD instruments is also the fact, that they are positioned in a rotating housing, which moves a relatively small logging speed. At inclined (with inclination larger than 50 º) and especially at horizontal wells, difficulties while making wire line logging measurements are quite often so that the MWD measurement represents the only solution.

Data of measurement for a well “Ormož G-1”

On the basis of the exploratory drilling results, for suitable geological interpretation of a deposit, it’s necessary to define

Table 1. Survey data at every 10 m and coordinate of survey points

Survey Point	Measured Depth d_m/m	Inclination i/°	Azimuth A/°	True Vertical Depth d_v/m	Coordinate of Points			
					±	N/m	±	E/m
1	993,0	14,5	144,5	983,58	-	61,52	+	28,10
2	1003,0	14,5	144,7	993,26	-	63,56	+	29,55
3	1013,0	14,5	144,5	1002,94	-	65,60	+	31,00
4	1023,0	14,5	145,0	1012,62	-	67,65	+	32,44
5	1033,0	14,5	146,8	1022,31	-	69,75	+	33,81
6	1043,0	14,4	146,8	1031,99	-	71,83	+	35,17
7	1053,0	14,4	146,8	1041,68	-	73,91	+	36,53
8	1063,0	14,4	147,8	1051,36	-	76,01	+	37,86
9	1073,0	14,3	149,3	1061,05	-	78,14	+	39,12
10	1083,0	14,4	150,7	1070,74	-	80,31	+	40,33
11	1093,0	14,4	152,2	1080,43	-	82,51	+	41,49
12	1103,0	14,4	153,3	1090,11	-	84,73	+	42,61
13	1113,0	14,4	154,4	1099,80	-	86,97	+	43,69
14	1123,0	13,2	151,1	1109,53	-	88,97	+	44,79
15	1133,0	13,2	159,0	1119,27	-	91,10	+	45,61
16	1143,0	13,2	167,1	1129,00	-	93,33	+	46,12
17	1153,0	13,2	174,1	1138,74	-	95,60	+	46,35
18	1163,0	13,2	180,6	1148,48	-	97,88	+	46,33
19	1173,0	13,2	186,0	1158,21	-	100,15	+	46,09
20	1183,0	13,2	193,2	1167,95	-	102,38	+	45,57
21	1193,0	13,2	200,8	1177,68	-	104,51	+	44,76
22	1203,0	13,2	208,8	1187,42	-	106,51	+	43,66
23	1213,0	13,2	215,6	1197,15	-	108,37	+	42,33
24	1223,0	13,3	221,9	1206,89	-	110,08	+	40,79
25	1233,0	13,3	227,6	1216,62	-	111,63	+	39,09
26	1243,0	13,3	234,1	1226,35	-	112,98	+	37,23
27	1253,0	13,3	240,6	1236,08	-	114,11	+	35,23
28	1263,0	13,4	249,8	1245,81	-	114,91	+	33,05
29	1273,0	13,4	258,5	1255,54	-	115,37	+	30,78
30	1283,0	13,4	265,2	1265,27	-	115,57	+	28,47
31	1293,0	13,5	272,2	1274,99	-	115,48	+	26,14
32	1303,0	13,5	279,9	1284,71	-	115,08	+	23,84
33	1313,0	13,6	286,5	1294,43	-	114,41	+	21,58
34	1323,0	13,6	294,6	1304,15	-	113,43	+	19,45
35	1333,0	13,6	301,6	1313,87	-	112,20	+	17,44
36	1343,0	13,7	308,8	1323,59	-	110,71	+	15,60
37	1353,0	13,7	315,8	1333,30	-	109,02	+	13,95
38	1363,0	13,7	324,5	1343,02	-	107,09	+	12,57
39	1373,0	13,7	332,5	1352,73	-	104,99	+	11,48
40	1383,0	13,7	338,6	1362,45	-	102,78	+	10,61
41	1393,0	13,7	344,4	1372,16	-	100,50	+	9,98
42	1403,0	13,7	350,2	1381,88	-	98,17	+	9,57
43	1413,0	13,7	355,9	1391,60	-	95,80	+	9,40
44	1423,0	13,6	1,2	1401,31	-	93,45	+	9,45
45	1433,0	13,6	7,1	1411,03	-	91,12	+	9,74
46	1443,0	13,5	12,5	1420,76	-	88,84	+	10,25
47	1453,0	13,4	24,9	1430,49	-	86,74	+	11,22
48	1463,0	13,3	38,4	1440,22	-	84,94	+	12,65
49	1473,0	13,3	51,5	1449,95	-	83,50	+	14,45
50	1483,0	13,3	60,6	1459,68	-	82,37	+	16,46
51	1493,0	13,4	71,1	1469,41	-	81,62	+	18,65
52	1498,0	13,4	81,3	1474,27	-	81,45	+	19,80

location of a well in the space (VIŽINTIN, 2008). Measurements are being done in points along axes of a well on certain distances. It's been applicable the data of the well "Ormož G-1" (Table 1). The well was made until profundity of 1500 m, in order to exploitation of thermomineral water from the carbonate rock collector (VESELIČ, 1996). The measurements were done, with the instrument EASTMAN W – 120 SINGLE SHOT. That survey instrument is single shot, which enables measurement in one point only at what, the instrument is pulled up after each measurement, on surface in order to reading the data which are measured. The accuracy of the instrument is: ± 0,3 ° for Inclination and ± 0,5 ° for Azimuth.

For comparing the data from survey points of different distance (10 m and 30 m) is chosen a segment of hole at 1000 m until bottom, because the collector rocks are located in this section.

A calculation of coordinate in survey points is performed by equation (*ROŠER R., 2008*):

$$P_{\begin{bmatrix} I \\ J \end{bmatrix}} = \begin{bmatrix} P_I \\ P_J \end{bmatrix} = \begin{bmatrix} \begin{bmatrix} x_I \\ y_I \\ z_I \end{bmatrix} \\ \begin{bmatrix} x_J \\ y_J \\ z_J \end{bmatrix} \end{bmatrix} = \begin{bmatrix} x_I \\ y_I \\ z_I \\ x_J \\ y_J \\ z_J \end{bmatrix} = \begin{bmatrix} \begin{bmatrix} \cos\alpha_I \sin i_I \\ \sin\alpha_I \sin i_I \\ \cos i_I \end{bmatrix} \\ \begin{bmatrix} \cos\alpha_J \sin i_J \\ \sin\alpha_J \sin i_J \\ \cos i_J \end{bmatrix} \end{bmatrix} = \begin{bmatrix} \cos\alpha_I \sin i_I \\ \sin\alpha_I \sin i_I \\ \cos i_I \\ \cos\alpha_J \sin i_J \\ \sin\alpha_J \sin i_J \\ \cos i_J \end{bmatrix} \qquad (2)$$

where:

x_I, y_I, z_I – coordinate of the point *I*/m

x_J, y_J, z_J – coordinate of the point *J*/m

α_I, α_J – azimuth at the points *I* and *J*/°

i_I, i_J – inclination at the points *I* and *J*/°

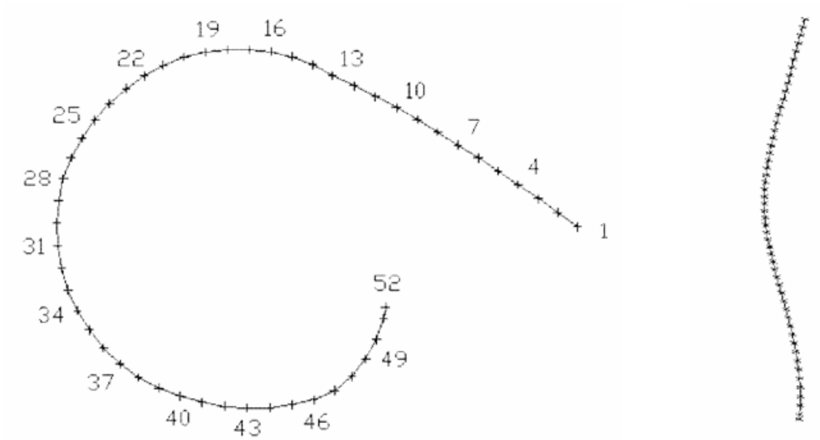

Figure 7. Trajectory of a well in horizontal surface and axonometric presentation (survey points on 10 m)

Table 2. Simulation of measurement in a well on 30 m and coordinates of the survey points.

Survey Point	Measured Depth d_m/m	Inclination i/°	Azimuth A/°	True Vertical Depth d_v/m	Coordinate of Points ±	N/m	±	E/m
1	993,0	14,5	144,5	983,58	-	61,52	+	28,10
4	1023,0	14,5	145,0	1012,62	-	67,67	+	32,41
7	1053,0	14,4	146,8	1041,68	-	73,92	+	36,49
10	1083,0	14,4	150,7	1070,74	-	80,42	+	40,14
13	1113,0	14,4	154,4	1099,80	-	87,15	+	43,37
16	1143,0	13,2	167,1	1129,00	-	93,83	+	44,90
19	1173,0	13,2	186,0	1158,21	-	100,64	+	44,18
22	1203,0	13,2	208,8	1187,42	-	106,64	+	40,88
25	1233,0	13,3	227,6	1216,61	-	111,30	+	35,78
28	1263,0	13,4	249,8	1245,80	-	113,70	+	29,26
31	1293,0	13,5	272,2	1274,97	-	113,43	+	22,26
34	1323,0	13,6	294,6	1304,13	-	110,49	+	15,85
37	1353,0	13,7	315,8	1333,27	-	105,40	+	10,89
40	1383,0	13,7	338,6	1362,42	-	98,78	+	8,30
43	1413,0	13,7	355,9	1391,57	-	91,70	+	7,79
46	1443,0	13,5	12,5	1420,74	-	84,86	+	9,31
49	1473,0	13,3	51,5	1449,93	-	80,56	+	14,71
52	1498,0	13,4	81,3	1474,25	-	79,69	+	20,44

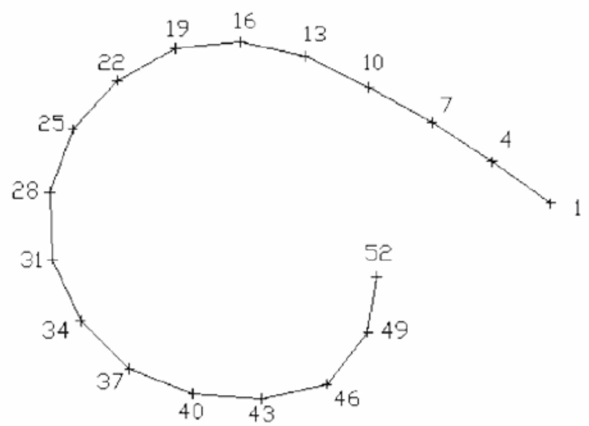

Figure 8. Trajectory of a well in horizontal surface and axonometric presentation (survey points on 30 m)

In order to comparing a trajectory of a well in a function of different sediment of survey points, the calculation of the coordinates were made, as though common measurement were simulated, on 100 ft, i.e. 30 m. The results of the coordinates of the survey points are presented on the table 2, whereas on the figure 8, the relevant trajectory of a well are presented in a horizontal surface and an axonometric presentation.

Comparing the coordinates of the same survey point either from Table 1 and Table 2, it's obvious that all linear deviation for survey point 52 amount to 1,87 m, but that all the greatest deviation for survey points 43 and amount to 4,40 m. Since her profundity 420 m in relation to adopted reference point 1, resulted that the deviation of a trajectory of a well in this point is a little more than 1% and only as a consequence of different sediment of survey points.

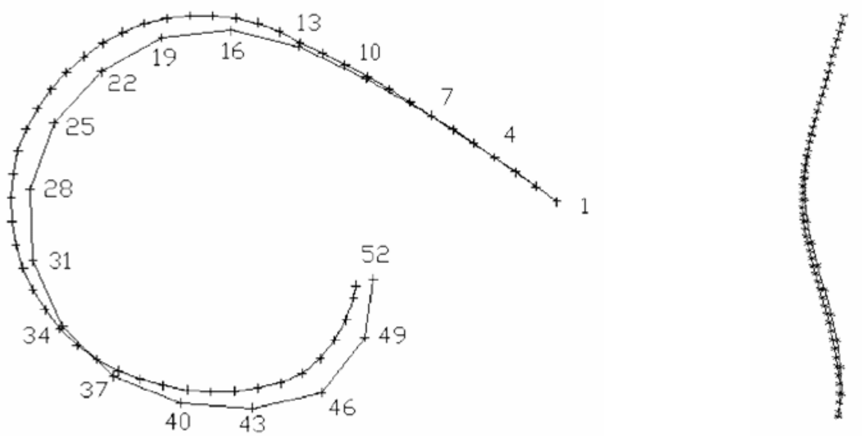

Figure 9. Comparative presentation of a well trajectory at different reciprocal distances of survey points

CONCLUSIONS

Measuring while drilling technology have increased drilling efficiency with obtaining direction related data, state of the borehole, drilling parameters and formation properties. This technology has become, in many cases an active part of the drilling operations. Future technological developments and improved measurement will make MWD essential part of drilling and formation evaluation.

At the example of the well "Ormož G-1" is presented indirectly advantage MWD in relation to conventional methods of measurement in a drill hole. Except of saving time, MWD allows greater profundity of measurement, by which the precision of controll the bore hole towards the desired target is going to increase. According to this it is obvious to pay attention that errors of measurement dimensions that are consequence of a precision of measuring device itself, are going to accumulate, so it can be loosing on the precision because of much greatness of profudity of survey points.

Since that engaging of service companies with MWD devices increase the expenses of drilling substantially, their application can be proposed in cases of a high accuracy that is requirement of trajectory well controll, i.e. at the drilling of a directional–horizontal wells.

References

[1] Burgess T., Voisin B. (1992): Advances in MWD technology improve real time data. *Oil & Gas J.*; Vol. 90, No.7, Tulsa.

[2] Desbrandes R. (1988): Status Report: MWD Technology. *Pet. Eng. Itl.*; Vol. 61, No. 9–11, Houston.

[3] Eickelberg D., Rischmüller W. et al. (1982): Controlled Directional Drilling, Preussag AG, Peine.

[4] Rao M. V., Fontenot J. E. (1988): MWD poised for future. *Oil & Gas J.*; Vol. 90, No. 4–5, Tulsa.

[5] Rošer R. (2008): Usmerjanje vrtin pri raziskovanju nafte, plina in geotermalne energije, Diplomsko delo, Naravoslovnotehniška fakulteta, Ljubljana.

[6] Tsai C. R. (1992): MWD Sensors Improve Drilling Safety And Efficiency. *Pet. Eng. Itl.*; Vol. 65, No. 9, Houston.

[7] Veselič M., Božović M., Štancar J., Vižintin G. (1996): *Raziskave za zajetje termalne vode na območju Ormoža*. Ljubljana: IRGO, 14 f., 9 pril., načrti, zemljevidi.

[8] Vižintin G., Viršek S. (2008): Analitical surface water forecasting system for Republic of Slovenia. Analitičen sistem napovedovanja pretokov površinskih vod v Republiki Sloveniji. *RMZ;* Vol. 55, No. 2, str. 215–224.

[9] Vukelič Ž., Šporin J., Vižintin G. (2004): Pore pressure. *RMZ;* Vol. 51, No. 4, str. 2117–2125.