System for definition of the pipeline diagram

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Abstract: - This paper deals with the definition of the oil pipeline diagram by means of navigation system of pig. The modern methods of pig location and navigation have been examined. The experience of aerospace technologies for construction of inertial system of navigation is used. The original methods of inertial system correction have been proposed. The block diagram of algorithm for automated data processing of pipelines inspection and reconstruction of their plan is developed.

Key-Words: - Pig, pipeline, plan, inspection

1 Introduction

The pipeline industry has done an excellent job in designing, constructing, and operating pipelines to assure their safe operation as well as the safety of the public. But as well as any technical system, pipeline can lose its function. Moreover, some of these pipelines were laid in the 1930s and 1940s, and many were constructed in the 1950s and 1960s. It is estimated that over 50% of the pipelines in the US are over 40 years old, with some up to 55 and 60 years old. [1].

In reviewing the incident statistics we find that for natural-gas transmission and gathering pipelines, for a 10-year period the average number of incidents reported was 82, with property damage $17,155,238. For the 12-years period (1984-1995) there was an average of 200 incidents reported of hazardous-liquid pipeline with property damage cost of $24,657,904 [1].

For reduction of the above-mentioned losses it is necessary to carry out periodic inspection of pipelines and eliminate revealed damages at early stages of evolution. The special tool for the decision of this problem is "pig". A pig is defined as “A device that moves through the inside of a pipeline for the purpose of cleaning, dimensioning, or inspecting”[2]. In an instantaneous way, this device carries out the diagnosis of the physical condition of a pipe. Among other data it is very important to know the location of this device during its movement and so the position of damage in the pipe, which has to be determined. Nowadays, different types of pigs for pipelines monitoring are used [3,4]. Intelligent pig was designed to deliver detailed information about a pipeline. Pig has very complicated navigation system.

Some pipeline obstructions are unavoidable, and are indeed a part of the jobs. Road and building constructions near pipelines put them in danger of being struck and dented by heavy machinery [5]. The incident summary by cause for gas transmission and gathering pipelines for 1995 is fairly consistent with previous years.

The leading cause of damage is from outside force (or from third party) and makes up 42% [1]. Soil erosion and traffic vibration can cause sags, buckles and ovalities. Because these are all dynamic situations changing on a daily basis, one cannot predict whether a pig will make it through the line.

Pipeline companies are feeling pressure from many sources to perform ever more thorough and detailed examinations of their systems. Toward this end, extensive pigging of all kinds is becoming an increasingly common activity worldwide, and an increasingly basic part of this pigging is the easy and accurate pig location and tracking.

There are active and passive methods of pipeline pig location and tracking such as: acoustic, mechanical, radioactive, sonic and active magnetic, but these methods have one important lack. That is, for determining the pig location the operator with the receiver has to be located above of it.

2 Proposed Solution

There are few systems to determine the pig location. The basis of these systems is the inertial navigation system that is of the same type used in aerospace industry. The opportunity on the application of space-born technologies in petroleum industry has occurred due to appearance of a new generation of inertial sensors, onboard computers and electronic memory [6].

Furthermore, it has been used angular speed (rate gyro) and acceleration sensors to determine the pig attitude, as well as the inclination and direction's angles of a pipe. Three basic advantages of new sensors allow applying them to determinate the pig site. Firstly, these sensors have small sizes permitting the system design with the sizes those are less than the minimum diameter of a pipe of about 6 inches. Secondly, they have small power consumption. This is an important point because when a pig moves inside a pipe, it consumes the electric power only from an independent accumulator. The speed movements of a pig could vary from 2 up to 8 m/sec, and the distance of the control could be up to 500 kilometres, that needs up to 3 days running along the way. Therefore it is very important that sensors do not consume so much electric power. Third, and may be the most important advantage of these sensors is their high accuracy and small drift. These three advantages make possible to design the independent navigation systems to work for a long time without melding of any correction.

The methods for positioning of the pig have been proposed in this paper. These methods are related with such sensors as pendulous and potentiometers and give an independent information about the angles that we use to improve the final position data.

3 System Structure

It is very important to optimize the division of data processing between onboard and ground computers for design of this type automated system. Also it is necessary to be guided by principles of the minimum sufficiency and take into account the accuracy of the maintenance [7].

Because the basic part of data processing would be carried out at the laboratory, it is necessary to write down the sensor information to the electronic memory. For instance, if the pig travelled a distance about 100 kilometres with an average speed about 2 m/sec during a time about 5×10^4 sec. With a minimum radius of pipe about 150 mm and the maximum radius of the pipe bend is equal to 4 diameters, the length of the arch in 90 degrees would be equal to about 1.9m. The angular speed of turn would be about 95 deg/sec. To perform the data recording with accuracy about 0.01deg/sec, it is necessary to use the frequency about 9.5 kHz. Thus, the memory volume to record only one parameter has to be about 950 GB. Practically it is inexpedient to have the onboard memory of such volumes, because it would be necessary to increase the equipment volume. Besides, it would cause the growth of the power supply.

By means of use the diminutive computers, it is possible to realize the one part of data processing onboard the pig practically in real time.

The computer summarizes the current angles magnitude with its initial size and writes down in memory not with frequency of calculation, but much less. To minimize the volume, weight and expenses of the different parts of the pig (like memory, battery, onboard computer) it is important to divide the procedures of the data processing between the onboard computer and laboratory equipment with the best rationality.

To construct the pipeline plan we need to have information about the distance and slope angles [7].

In the proposed method the distance can be measured by means of use two ways [8]:

- With help of an odometer.
- By integration of the acceleration measured during of the experiments.

The slope angles of the pipeline can be measured by means of:

- two potentiometers, installed on both axes of Cardan joint that combines two parts of the pig.
- four odometers, those are installed equally perpendicular.
- inertial system (three rate gyros and two accelerometers) that integrates the angle speeds.

In the case of the potentiometers the system can directly measure the slope angles. It is one type of angle information.

In the second case (odometers), the measurements can be realized because internal and external walls of the pipe have different lengths when pipeline has turn.

In the third case we have the standard inertial system. In all cases, because a pig can roll about his horizontal axis, it is necessary to know the turn angle Φ. So to measure the roll, we have proposed to use the inclinometers. Another possibility to measure a pith angle (Θ) is to use the inclinometer inside the pendulum. In this case the axis of the rotation of the pendulum has to be congruenting with the longitudinal axis of the pig.

Data correction can be accomplished with the help of a reference stations. So, during the experiment, for every 5 or 6 km, above the pipeline it is necessary to install the reference station. The real coordinates of the reference point are defined by means of Global Positioning System (GPS) working in the differential mode before the test. These stations consist from electronic location system to fix the time when pig passes underground.

The block diagram of the proposed algorithm is presented in the Figure 1, where: θ_i , ψ_i , ϕ_i are pitch, yaw and roll angles; L is distance; λ and φ are longitude and latitude; index 1 for parameters of inertial system; index 2 for parameters of potentiometers-inclinometers system; index 3 for parameters of inclinometers system; index 4 for parameters of odometers system and index 5 for parameter of inclinometer inside pendulum.

The very known strapdown concept [6] can be realized in form of essentially a complementary filter, in which the primary measurements are the three angular rates ***P, Q,*** and ***R*** and the aiding measurements are the two perpendicular acceleration measurements a_{xm}, and a_{ym} . The algorithm is based on the Euler differential equations. The equations (1) present the relation between the Euler angle rates $\dot{\Phi}, \dot{\Theta}$ and $\dot{\Psi}$ to the angular rates ***P, Q*** and ***R*** measured by body-mounted rate gyros concerning inertial space.

$$\dot{\Phi} = P + Q sin\Phi tan\Theta + R\cos\Phi tan\Theta$$

$$\dot{\Theta} = Q\cos\Phi - R sin\Phi \qquad (1)$$

$$\dot{\Psi} = Q(sin\Phi / \cos\Theta) + R(\cos\Phi / \cos\Theta)$$

The integration of the values $\dot{\Phi}, \dot{\Theta}$ and $\dot{\Psi}$ would yield the computed Euler angles Ψ,Θ and Φ, which

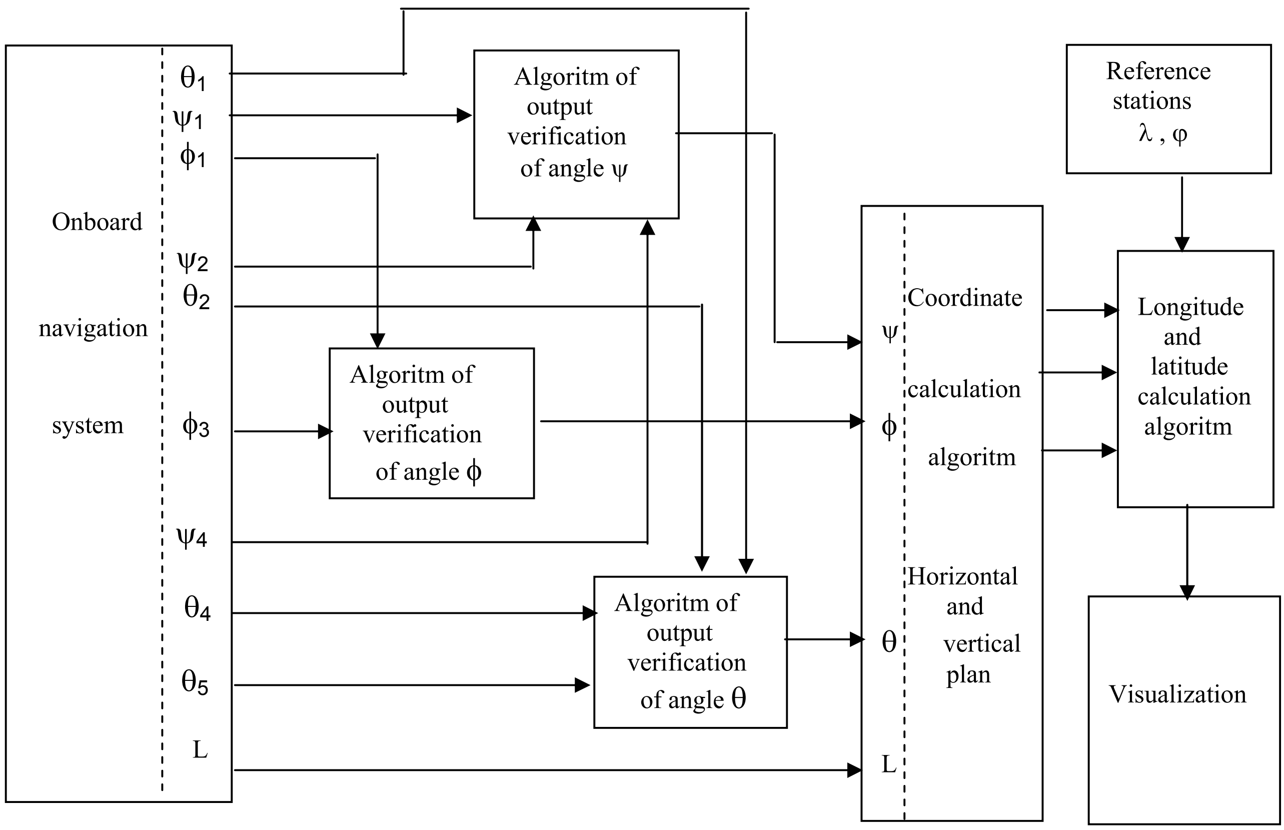

Figure 1. The block diagram of the pipeline plan construction algorithm

clearly are referred to inertial space. These, however, would accumulate errors due to the rotation of Earth, the motion of the vehicle, and the gyro drifts

The correction of inertial system can be carried out with the help of angles calculated from potentiometer and odometers systems. The two potentiometers, installed on both axes of Cardan joint that combines two parts of the pig and can directly measure the pitch and yaw angles. The principle of work is presented in the Figure 2.

The four odometers are installed equally perpendicular. In this case the measurements can be realized because the internal and external walls of the pipeline have different lengths when the pipeline has turn.

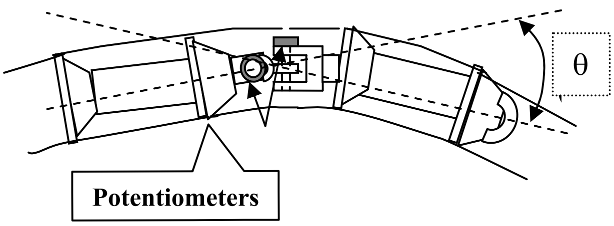

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Fig. 2. Principle of angles measurement by means of potentiometers

If the roll angle Φ is not equal 0 it is necessary to determine it and to apply coordinates transformations.

The roll angle Φ is possible to obtain by means of other method with used inclinometer (pendulums) as sensors [9]. Physically, the range of the sensors manufactured in industry is $\pm 90°$. Also, each sensor has output signal in sine form. In the area of +90° to +270° the magnitude of output voltages of the sensor is the same that in the area of ± 90°.

Therefore it is necessary to determine in which area works this sensor and after to take the magnitude of it as true. For this aim it is necessary to give an axial displacement between two sensors. The optimum axial displacement between two pendulums Φ1 and Φ2 is 60°. In this case the calculation algorithm of the angle has such form [9]:

If $0 \le \Phi1 \le 90$ and $\Phi2 \le 0$, then $\Phi = \Phi1$,
otherwise If $0 \le \Phi1 \le 90^o$
and $0 \le \Phi2 \le 60^o$.
(for range $0^o \div 60^o$),

then $\Phi = 60^o + \Phi2$.
(for range $60^o \div 120^o$),
otherwise $\Phi = 180^o - \Phi1$
(for range $120^o \div 180^o$),
If $\Phi1 < 0$ and $60^o < \Phi2 \le -60^o$
then $\Phi = -(120^o + \Phi2)$
(for range $-180^o \div -60^o$),
otherwise $\Phi = \Phi1$
(for range $-60^o \div 0^o$).

The advantage of this algorithm is used practically linear zones of each sensors. On the figure 3 a design of the pig is shown. This equipment realizes principles and algorithms described above

4 Conclusions

The described system to automated data processing of pipeline inspection and construction of their plans allows considerably decreasing of the expenses on the diagnosis and service of oil pipelines.

The developed algorithm to calculate of an angular estimation on the base of redundant angular data allows by means of use the additional algorithmic procedures to apply the sensors with more large drift. Moreover, in comparison with the existing systems, the given system has the greater accuracy for coordinates definition due to internal correction. External sources of correction are not necessary for its functioning.

Simulations and analysis of the results of different experimental tests with sensors have shown that the proposed and analyzed navigation method, sensors and algorithms provide sufficient capabilities to realize the presented navigation system and to determine precisely a position of the pipeline defects.

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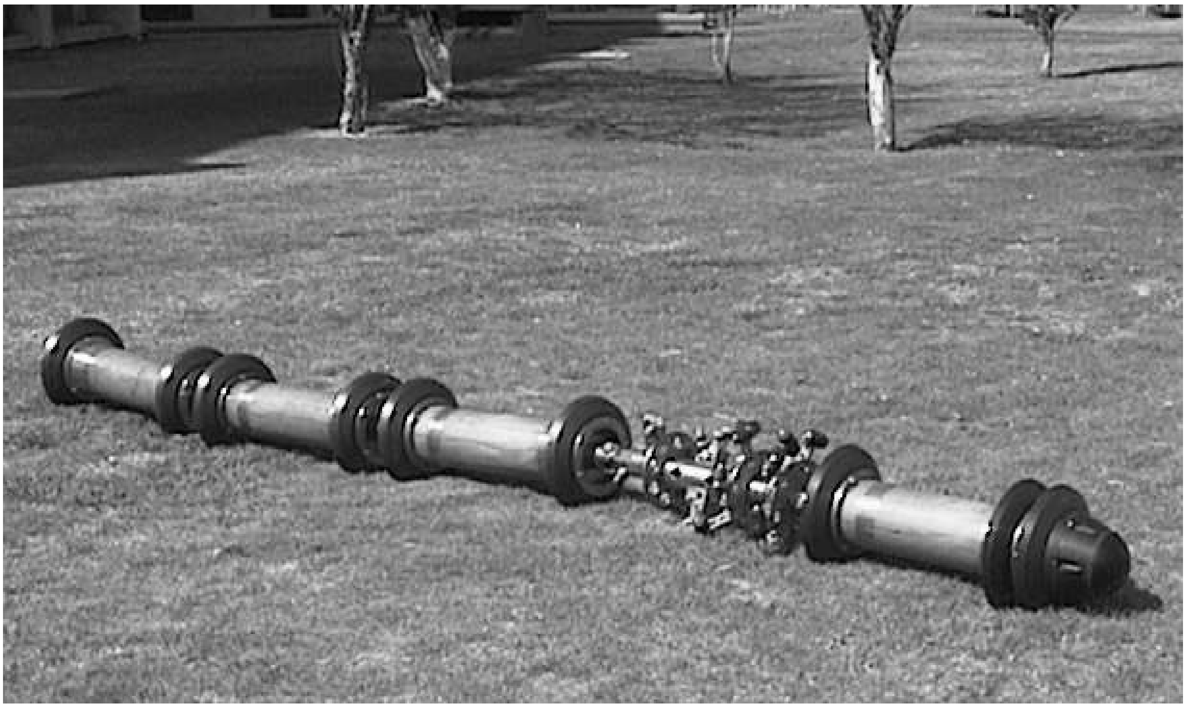

Fig. 3. The 12" pig-geocaliper with navigation system

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