Application of Fourier Descriptors and Person Correlation for Fault Detection in Sucker Rod Pumping System

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***Abstract*—This paper presents a study of new proposal for down-hole dynamometer cards patterns for the automatic fault diagnosis of Sucker Rod Pumping System. The accurancy and quick identification of down-hole problems is essential to the risk decrease and production improvement of petroleum industry. The main idea is a card recognition through of digital image processing (Fourier Descriptors) and statistical (Person Correlation) tools. Successful results were reached when this proposal was applied in simulated cards and PETROBRAS real cards.**

I. Introduction

The Sucker Rod pumping is the most common form of artificial lift in the world [1], [2] (Schirmer et al., 1991; Alegre et al., 1993). It is estimated that 90% of artificially lifted wells use Sucker Rod pumping systems (Tripp, 1989; Nazi and Lea, 1994). In Brazil, 64% of all producing wells are on rod pump (Rutacio, 2002). In practice, the analysis of Sucker Rod pumping system is through of a card. This card is called dynamometer card. With this card is possible to get the down-hole condition of rod-pumped wells. The dynamometer card is a plot of load *versus* position that reflects the actual pumping conditions (Rogers et al., 1990; Barreto et al., 1996). While the system operation, the card can assume several shapes that might be a normal operation or fault situations. The Sucker Rod System fault diagnosis is a visual interpretation process (Dickinson and Jennings, 1990). However, this approach can be influenced by several factors, such complex behavior of system, diversity of dynamometer card shapes, and experience and skill of engineer.

Today, the main petroleum engineer of the production field is responsible for more than a hundred wells. In this case, the traditional process of interpretation is not suitable for the prompt diagnosis of the down-hole conditions. The accurancy and quick identification of down-hole problems is essential to the risk decrease and production improvement of petroleum industry. Because the fault diagnosis of sucker rod pumping system is a process of pattern recognition of dynamometer cards, several works using artificial neural network in recognition and classification has been make to improve the accuracy and efficiency of sucker rod pumping system fault diagnosis.

The recognition and classification of objects based on their visual similarity has become a central task in current industrial imaging systems. With increasing amounts of realworld image data to be processed and stored, the development of powerful retrieval tools also has become necessary in machine vision applications. This work proposes a new proposal to analyse and to diagnose any Sucker Rod Pumping System based in the following points:

- A better description model;
- A statistical recognition.

Therefore, effective shape description is essential in retrieval systems. The Fourier descriptor (FD) is probably the best-known boundary-based shape descriptor. It has been proven to outperform most other boundary-based methods in terms of retrieval accuracy and efficiency. (GetPDFServlet) In addition, the recognition is being done through a correlation, a simple statistical principle, that suggests a cause-effect relation between two variables, in other words, the relation between the well card and pattern card.

This work is divided in seven sections. In the next, it is explained the sucker rod system and any cards patterns are presented with their means. The third section, it explains a boundary descriptors, empathising the Fourier Descriptors and, after that, it shows a correlation principle that was used. The model proposed is showed in fifth section and, after that, the results reached. At last, the conclusions are commented.

II. Sucker Rod Pumping

In the history, the first artificial lift method, that appeared in the oil industry, was Sucker Rod Pumping, appearing after that the oil industry birth. The importance of method is showed in the number of installation that are operation in world. The Figure 1 presented a Sucker Rod Pumping Unit.

The great success of Sucker Rod Pumping System is linked with low cost in: investment, maintenance, flow and deep flexibility, good energetic efficient and the possibility to operate with fluids of several composition and viscosity in the large temperature range.

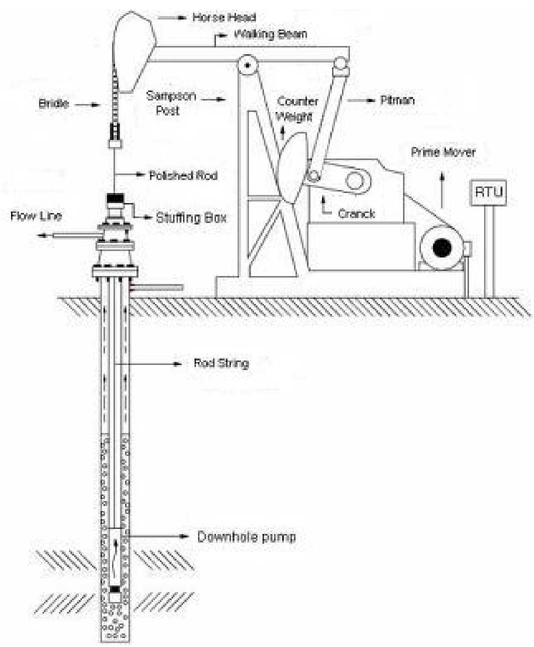

Fig. 1. Sucker Rod Pumping Unit

The main advantages of Sucker Rod Pumping are the simplicity of: operation, maintenance and new installation project. In the normal condition, this method can be used until the end of field life productive and its pumping capacity can be changed in function of well behavior. But, the main advantage is the lowest cost/production relationship during of field life productive.

A. Components of Sucker Rod Pumping

1) Downhole Pump: The Downhole Pump is positive displacement pump, in other words, when the fluid get in suction, it do not return. Its performance is based in the displaced fluid volume.

Because of volumetric efficient, generally, the surface flow is lower than volumetric displacement. The volumetric efficient always is lower than 100% because any problems, like: fluid slip through piston, free gas in downhole pump, formation volume factor(B_o) and mechanic wear in the valves. Values between 70% and 80% for volumetric efficient are accepted like normal. The volumetric efficient (E_v) can be the relationship between total liquid flow (Q_b) and the volumetric displacement, subtracting system wear and/or leaking.

There are two pumps, that the both basic difference is the installation manner in the well. The pumps are:

Tubing pumps: These are installed in the well with production tubing, where the pump liner is a production tubing part. The piston and travel valve are screwed in the end of rod string. For a tubing diameter, these pumps showed a bigger pumping capacity. If there is a problem in the liner pump, the main disadvantage is to move whole production tubing.

Insert pumps: These have all parts connected with rod string and these need a mechanism that to hold the liner pump to production tubing. The main advantage is to change whole pump through of a simply movement of rod string.

2) Rods String: The string rod is considered the vital part of Sucker Rod Pumping System. This is responsible to provide the surface energy to downhole pump. The rods receive cyclic charges and work in abrasive and corrosive environments. The rod behavior have a fundamental impact in the lift efficiency. So, a good-sized project of rods can avoid major damages.

The string rods is a several rods sequence connected to each other to reach deep downhole pump. There is a API Standard (*API SPEC* $11B$) that the objective is specify rods.

3) Sucker Rod Pumping Unit: A unidade de bombeio converte o movimento de rotao do motor em movimento alternado requerido pela haste polida, ao mesmo tempo em que a caixa de reduo reduz a velocidade de rotao do motor para velocidades de bombeio fisicamente possveis.

A unidade de bombeio geralmente instalada sobre uma base de concreto ou sobre perfis de ao. A base permite o alinhamento dos componentes da unidade, principalmente, o trip, a caixa de reduo e o motor. O trip (sampson post) pode ter trs ou quatro pernas e deve suportar grandes cargas na haste polida. O mancal de sela, logo acima do trip, o ponto piv para a viga, ou seja, o movimento da viga em torno deste eixo.

A cabea da UB (horse head) permite atravs do cabresto (bridle) movimentar a haste polida. Sua forma estrutural permite uma curvatura que realize o movimento requerido pela bomba de fundo.

As manivelas esto localizadas nos dois lados da caixa de reduo e giram a baixas velocidades, transmitindo atravs das bielas o movimento para a viga. A distncia do eixo da manivela ao mancal da biela ou mancal de cauda define o curso da haste polida. Este curso pode ser modificado em funo da posio de fixao da biela.

Os contrapesos (counterweights) esto fixados nas manivelas, tendo como funo balancear a unidade de bombeio, minimizando-se esforos no motor. No curso ascendente o motor bastante solicitado para elevar os fluidos acima do pisto. J no curso descendente, a fora da gravidade responsvel pelo movimento das hastes. Assim, o motor funcionaria de forma cclica, o que prejudica sua vida til. A fim de minimizar este tipo de problema so utilizados os contrapesos na manivela ou na viga.

4) Dynamometer Card: Uma carta dinamomtrica nada mais do que um grfico representando os efeitos gerados pela carga atuante na bomba, durante um ciclo de bombeio. Existem dois tipos de cartas dinamomtricas, a carta de superfcie e a de fundo. As cargas so registradas na superfcie atravs de dinammetros e no fundo do poo atravs de dispositivos especiais ou atravs de modelos matemticos.

As cartas dinamomtricas esto entre as principais ferramentas de anlise e avaliao das condies de bombeio, registrando as cargas na haste polida ou no fundo em funo do curso das hastes.

 possvel observar diversas condies de bombeio atravs da carta dinamomtrica. As mais importantes informaes extradas

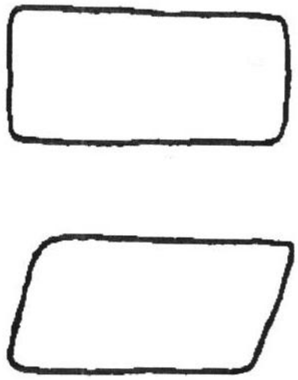

Fig. 2. Normal Patterns

da anlise de cartas dinamomtricas so:

- determinao das cargas que atuam na unidade de bombeio e na haste polida;

- determinao da potncia requerida para a unidade de bombeio; - ajuste do contrabalano da unidade de bombeio; - verificao das condies de bombeio da bomba e vlvulas, e; - deteco de condies de falha.

B. Reference Cards Patterns

In this subsection, any Sucker Rod Pumping System cards are presented. Each card showed was chosen based in the mains problems of oil fields and they can be found in others previous works. (Colocar aki referencias) These presented cards are some reference patterns for the proposed model in the most forward section.

1) Normal Operation: The normal pumping is represented for shapes in the Figure 2, if the rod is anchored or not. This pattern is associated to follow characteristics:

- High volumetric Efficiency;
- Low interference of gas;
- Low or medium suction pressure.

2) Fluid Pound: These patterns presented in Figure 3 are associated to follow characteristics:

- Low suction pressure;
- Low interference of gas;
- Blocked Pump Suction.

3) Valve Leak: The Figure 4 shows the patterns that happen when there is a leak in down-hole valves.

4) Pump Hitting: There are some problems of down-hole pump that are showed through Figure 5. These problems are pump hittings in side of sleeve, in the top or the down.

III. Theoretical Base

A. Boundary Descriptors

The shape descriptors are mathematical methods that represent the object or region shape. The descriptors are separated in two groups (Gonzalez-Livro):

- Contour-Based descriptors;

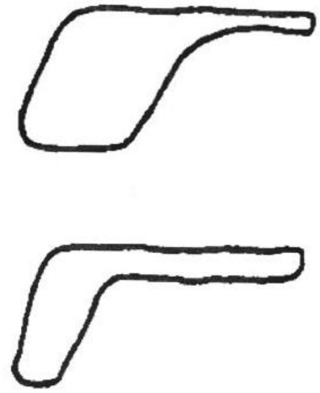

Fig. 3. Fluid Pound Patterns

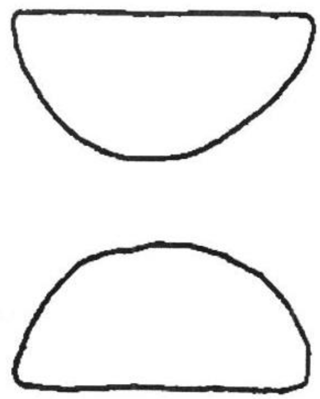

Fig. 4. Valve Leak Patterns

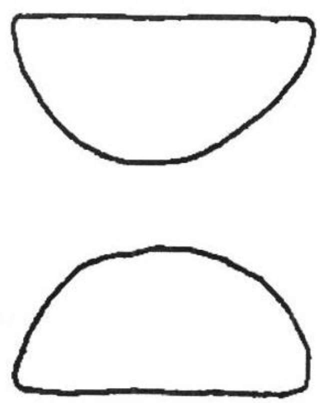

Fig. 5. Pump Hitting Patterns

- Regional descriptors.

The boundary descriptors describe the object shape and are based in the contour. The internal shape are described by regional descriptors. The ideal descriptors may have any of the following invariant characteristics:

- Translation;
- Rotation;
- Scale;
- Begin point.

In this work, it have been used a shape descriptor that called Fourier Descriptors.

1) Fourier Descriptors: In addition to good retrieval and classification performance, the main advantages of Fourier Descriptors are that they are compact and computationally light, they are easy to implement, their matching is straightforward, and their sensitivity to noise is low.

The contour-based shape description is based on one-dimensional boundary function (shape signature). Let (x_k, y_k), where $k = 0, 1, 2, ..., N-1$ represents the object boundary coordinates, in which N is the boundary length. Complex coordinate function $z(k)$ (Ref. 2) expresses the boundary points in an object centered coordinate system:

$$z(k) = (x_k - x_c) + j(y_k - y_c)(1)$$

in which (x_c, y_c) is the object centroid.

Fourier descriptors can be formed for the boundary function $z(k)$ using the Discrete Fourier Transform (DFT):

$$F_n = \frac{1}{N}\sum_{k=0}^{N-1} z(k)e^{-\frac{j2\pi nk}{N}}(2)$$

for $n = 0, 1, 2, ..., N-1$ and F_n are the transform coefficients of $z(k)$. The descriptors can be made rotation invariant using the magnitudes of the transform coefficients, $|F_n|$. The scale can be normalized by dividing the magnitudes of the coefficients by $|F_1|$.

B. Correlation Analysis

In probability and stochastics process, the correlation show the force degree and direction of linear relationship between two random variables. In general statistical usage, correlation refers to the departure of two random variables from independence. In this broad sense there are several coefficients, measuring the degree of correlation, adapted to the nature of the data.

A number of different coefficients are used in several situations. The most known is the Pearson correlation coefficient, or simply Pearson correlation, which is obtained by dividing the covariance of the two variables by the product of their standard deviations.

1) Person Correlation: The Person correlation (or "product-moment correlation coefficient", or also "r of Pearson") measure the correlation degree and the direction between two variables of metric scale. This coefficient is represented for r and can be between -1 and 1. So, r can be analysed of the following manner:

- $+1$: It means a perfect correlation and the variables are in the same direction;
- -1: It means a perfect correlation too, but, in this analysis, the variables direction is opposite.
- 0: In this case, the variables does not have a linear dependence. However, there can be a non-linear dependence. So, this result may be analysed by other methods.

In other words, the signal of result correlation shows if the correlation is positive or negative and the proportion variable shows the correlation force.

The Person correlation coefficient is calculated according to next formula:

$$\rho_{X,Y} = \frac{\mathrm{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E((X-\mu_X)(Y-\mu_Y))}{\sigma_X \sigma_Y},$$

Where E is the expect value operator and cov means covariance. This equation can be written:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2} \cdot \sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

Where x_1, x_2, ..., x_n e y_1, y_2, ..., y_n are measure values both of variables. Moreover, x_n can be written:

$$\bar{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i$$

And y_n can be:

$$\bar{y} = \frac{1}{n} \cdot \sum_{i=1}^{n} y_i$$

This variables (x_n and y_n) are arithmetics means both of variables x and y.

IV. Proposed Model and Results

O modelo prope o uso de ferramentas muito muito utilizadas em reconhecimento de padroes em processamento de imagens. Neste artigo estas ferramentas sao utilizadas na deteccao de falhas em um dos equipamentos mais utilizados na industria de petroleo.

A. Proposed Model

O modelo proposto esta baseado na selecao de padroes, como ja apresentados em seccao anterior. Estes modelos sao processados, gerando um descritor de fourier para cada padrao e para a carta gerada do campo. O descritor de fourier gerado a partir da carta do campo eh correlacionada com cada descritor de fourier referente a cada padrao. A saida de cada correlacao comparada em uma funcao de maximo que seleciona o padrao mais proximo do descritor de fourier da carta de campo.

A Figure 6 showed a information flow in the proposed model.

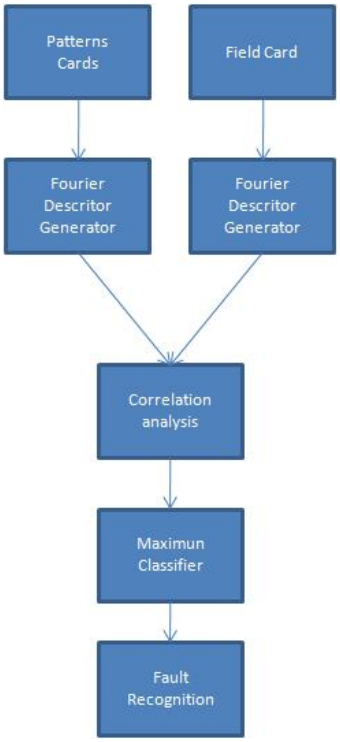

Fig. 6. Proposed Model Flow

B. Results

Foram analisadas 102 cartas dinamomtricas com falhas, acima descritas, e com operacao normal. Destas 102 cartas, obteve-se um percentual de superior a 95% de acerto.

V. Conclusion

O modelo proposto apresentou uma eficiencia alta para as cartas de campo apresentadas e mostrou-se muito robusto a problemas inerentes a processamento de imagens, como: rotacao, translacao e escala.

Para trabalhos futuros, deseja-se desenvolver uma ferramenta de predicao destas falhas, baseadas na analise das frequencias fundamentais de cada padrao de falha. Desta forma, o engenheiro de campo ser capaz de melhor gerenciar os seus equipamentos, bem como predizer e planejar a manutencao quando houver a falha.

Acknowledgment

The authors would like to thank...

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