Methods of increasing efficiency and maintainability of pipeline systems

V A Ivanov, S M Sokolov and E V Ogudova

Industrial University of Tyumen, 38 Volodarskogo St, Tyumen, 625000, Russia

E-mail: ivanov_v_a@list.ru

Abstract. This study is dedicated to the issue of pipeline transportation system maintenance. The article identifies two classes of technical-and-economic indices, which are used to select an optimal pipeline transportation system structure. Further, the article determines various system maintenance strategies and strategy selection criteria. Meanwhile, the maintenance strategies turn out to be not sufficiently effective due to non-optimal values of maintenance intervals. This problem could be solved by running the adaptive maintenance system, which includes a pipeline transportation system reliability improvement algorithm, especially an equipment degradation computer model. In conclusion, three model building approaches for determining optimal technical systems verification inspections duration were considered.

1. Introduction

The possibility of the straightforward optimal pipeline transportation system (PTS) structure choice is eliminated by a typical for pipeline systems (oil, gas and other pipelines) tendency for recurrent process conditions to change, by various technical-and-economic indices and performance indicators for different trunk pipelines. All the mainly used technical and economic indices, playing a key role in determination of an optimal product supply system structure, can be divided into two classes. The first class includes indices, depending on the main properties of the environment, to which key PTS elements are directly related [1]. These include indices that feature the mode of conveyed fluid consumption: maximum capacity operating hours, delivery schedule density ratio, delivery schedule peaking ratio (ratio of minimum pipeline capacity to the longest maximum or minimum pipeline capacity operating duration), technical-and-economic indices of the resources used, pipeline environment conditions. The second class includes indices, displaying properties of a single pipeline as a PTS unit. The main pipeline properties can be defined variously, depending on the kind of connections (external or internal) they present. Therefore it would be convenient to divide the second class technical-and-economic indices into two groups: indices, determining external connections (connections between PTS and other national economy systems), and indices, mainly determining internal connections (connections between pipeline within PTS) [2].

According to the main principles of the systematic approach when selecting an optimal PTS structure, let us indicate these indices of each of the two second-class technical-and-economic indices groups that turn out to be necessary and possible to be considered in the current circumstances. It is obligatory to consider national economic costs to optimize the process of choosing optimal PTS structure models for the following reasons: firstly, to fully access all the national economic costs associated with PTS operating and, secondly, to choose the most appropriate pipeline system to internal and external connections [3]. On the one hand, first-class technical-and-economic indices (i.e.
indices that determined a mode of a conveyed fluid consumption) impose restrictions on the mathematical model of an optimal PTS structure and, on the other hand, directly or indirectly affect key management indicator – reduced costs. As reduced costs are influenced by the intensity of deterioration of equipment (which fully complies with the mode of a conveyed fluid consumption due to the specific characteristics of pipeline transportation), its direct impact on first-class technical-and-economic indices is mostly manifesting in changing the fixed and variable components of reduced costs. Second-class technical-and-economic indices determine reduced costs – management performance indicators of PTS operation. Pipeline transportation systems currently display certain traits consistent with huge cybernetic systems (a multitasking performance, complex associations, a hierarchy, probabilistic systems, a continuous development through time and a feedback mechanism) [4]. That is why these systems control has become more difficult. The key targets of PTS operation are rather connected with system control and environmental issues than with achieving high cost-effectiveness. This is because the achievement of mentioned targets is a mandatory requirement for an optimal and sustainable development of the national economy as pipeline transportation systems are an inseparable part of the national economy structure. The development of improved methods for optimizing the technical-and-economic structure of complex pipeline transportation systems is a critical task for its development management.

2. Methods

It is considered that PTS operating efficiency is provided when the following targets are achieved:

- maximum reliability of the fluid conveying;
- minimum capital investments;
- minimum annual costs;
- maximum pipeline adjustment range;
- minimum blackout probability;
- minimum consumption of scarce resources;
- minimum time required for raising capacity to a throughput capacity level;
- minimum time required for construction and putting into operation;
- minimum human labor costs while operating PTS.

The PTS maintenance strategy is determined by its specific purpose and structure. The selected maintenance strategy must fit in the existing PTS maintenance process.

In order to select the PTS maintenance strategy, the maintenance process is described further. Pipeline equipment and linear part are routinely inspected after a certain period of time. In the case of PTS failure, the emergency recovering repair is carried out; if not, the scheduled preventive maintenance is provided. After putting PTS into operation the scheduled current maintenance is carried out throughout period T; if PTS failed during period T, the emergency repair is carried out. This process continues until the major repair and then the cycle is repeated again [5, 6].

Let us consider stochastic process \( F(t) \), describing the state of the system at an arbitrary moment in time \( t \).

Function \( F(t) \) in the case considered above will acquire the following values:

\[
F(t)=
\begin{cases}
  F_0, & \text{if at moment } t \text{ the system operates normally;} \\
  F_1, & \text{if at moment } t \text{ a hidden failure occurs;} \\
  F_2, & \text{if at moment } t \text{ an emergency preventive repair is conducted;} \\
  F_3, & \text{if at moment } t \text{ scheduled preventive maintenance is conducted during storage;} \\
  F_4, & \text{if at working moment } t \text{ the system is at a state of an emergency repair;} \\
  F_5, & \text{if at moment } t \text{ a current maintenance is conducted;} \\
  F_6, & \text{if at moment } t \text{ the plant control system is launched after repair.}
\end{cases}
\]
The process of technical state changes can be displayed on a graph, which demonstrates the necessary PTS maintenance strategy. There are seven PTS maintenance strategies.

Strategy A: full system recovery is provided only after an evident failure.

Strategy B: full system recovery is provided at the moment of failure or at the scheduled time.

Strategy C (storage strategy): full system recovery is provided only at the scheduled time despite system failures.

Strategy D: full system recovery is provided after an evident failure or at the scheduled time.

Strategy E: after a separate failure demonstration only the failed component is replaced.

Strategy F: the system is fully restored when operating time reaches the set level; after a failure, only the failed component is replaced.

Strategy G: the system is fully restored after a failure or when the operating time reaches the set level.

The conditions of use of B and C strategies meet the requirements of PTS maintenance. Consequently, typical B and C strategies are suitable for creating a system for PTS maintenance. The combination of transient graphs forms a supergraph, reflecting a required strategy of PTS maintenance.

There are special purpose operational services which prevent and eliminate failures of pipeline equipment and linear part. The current system of PTS maintenance is based on a set of interrelated provisions given in reference documentation [7-9].

PTS maintenance is divided into two types:

− scheduled maintenance, which is provided periodically to exclude the increase in failure rate;
− unscheduled maintenance which is provided only after failures (emergencies) to restore PTS.

The first type of PTS maintenance, including routine inspections and preventive maintenance, is among important ways of maintaining PTS reliability while continuous system operation. However, due to non-optimal values of PTS components maintenance intervals, lack of a failure forecasting system and misallocation of backup components, this type of PTS maintenance turns out to be not sufficiently effective. In order to select the PTS maintenance strategy, the maintenance process is described further. The issue of PTS components failure impact assessment is considered further to explain the necessity of optimal PTS operating. Any PTS component failure leads to an optimal operational mode disturbance; meanwhile, the emerging productivity loss affects on fluid conveying efficiency. After a PTS component failure, the technological process comprises three stages:

− process shutdown, i.e. switch to the maintenance mode;
− the maintenance mode itself;
− process launch – process switch to the normal operational mode after PTS component maintenance.

Failure effects may be measured by an average PTS failure cost (the value of an average productivity loss due to the failure). The total duration of a shutdown and a maintenance mode composes the amount of time for PTS restoration in an emergency mode. Let us consider the components of a recovery time in detail. PTS component failure can be eliminated in two ways: with or without replacing the faulty component.

In the first case, failure can be eliminated by operational services on the spot. Stages of maintenance work include:

− administrative time $\tau_0$;
− troubleshooting time $\tau_s$;
− fault elimination time $\tau_f$ and launching time $\tau_p$.

For the majority of pipeline transportation systems, a borderline case is typical: some failures are eliminated by operating staff and some by centralized repair stations if specific maintenance conditions are required. Replacement parts are installed instead of PTS components in need of centralized repair.
In order to operate PTS efficiently, the adaptive maintenance system, which includes PTS reliability improvement algorithm, should be used. The basis of the algorithm is PTS components failure stochastic process computer modeling. The modeling can be carried out when specific models (also called ‘energy sources interfiled and trunk PTS components maintenance models’) are used. The models are built to determine sustainable methods of the main reliability parameters improvement [10-12].

Maintenance models make consideration of failure elimination process possible; well-timed failure elimination creates opportunities for hydrocarbon PTS reliability improvement. Maintenance computer model is mainly determined by backup components availability and pattern of use, failure location and elimination methods, the ratio of fault-free operation time to maintenance duration. The selection of indices, used in PTS maintenance models, is important. Modern efficient methods of calculating PTS interrepair maintenance terms are based on usage of the dependence of predictive parameters on time. Due to arrange PTS maintenance, it is necessary to define the system and its components reliability parameters. In this case, the use of adaptive algorithms, providing combined operational reliability data capturing and system service, produces a large impact.

Failures can be located during specific PTS inspections named ‘verification inspections’ (VI). In addition, it is essential to solving inspection scheduling problem (i.e. the problem of inspection frequency determination) to minimize the expected value of costs associated with failures and inspections [13].

VI models describe degrading systems behavior. Because the degradation is a random process, the valid system state can only be identified during VI. Preventive maintenance of degrading PTS can be performed in two ways: regularly with fixed frequency or after measuring system parameters that are gradually changing while equipment degradation [14]. In the first case, only prior information on system state is used; the second method is based on the use of posterior information.

When applying the statistical modeling method (Monte Carlo method), system maintenance parameters are to be analyzed from certain probabilistic characteristics of PTS operation elementary process. For that purpose, the analyzed object probability prototype is built and then it is randomly and repeatedly implemented. The processed result serves as the problem-solving.

3. Conclusion
In summary, three model building approaches for determining optimal technical systems VI duration were considered. Each approach has both advantages and disadvantages. There are three ways to define an optimal PTS maintenance scheme.

In the first scheme, the maintenance is held after the fault-free operation. If a failure occurs before time, scheduled maintenance is held simultaneously with the emergency repair. After any kind of maintenance, PTS is considered as renewed. Then, the next schedule maintenance must be planned.

In the second scheme, scheduled maintenance is held after 25000 hours independently of a number of emergency failures happened between scheduled maintenance. After emergency failure only partial repair is held; after scheduled maintenance, PTS is considered as renewed.

The third scheme for PTS scheduled maintenance can be realized. In this case, the time period between scheduled maintenance will depend on the amount of PTS failures and on physical-chemical-mechanical PTS components condition. The third scheme is applicable to the so-termed degradation PTS failures. Degradation failures are characterized by a gradual decrease in the functionality of components in time. Degradation failures are the most frequently occurred failures. Based on fault inception statistical regularity, it is possible to prevent initiation of degradation failures and, partly, of random failures. PTS failures can be prevented if components predictor is known and if the gradual components structure change obeys a certain law.

A predictor variable is a variable that characterizes changes in component technological structure at any specific time and allows controlling component reliability margin.

Certain performance limits of PTS components allowable to control in operation are usually set. Components performance deteriorates over time, which means that component is close to breakdown.
That might give an opportunity to set a preliminary PTS predictor level at which the faulty component should be found and then replaced.

To change the faulty PTS component, it is necessary to have backup components. That is why, an optimal duration of schedule maintenance model should include a model for an optimal backup components quantity determination. These class models are considered under the question of redundancy optimization.

In this case, the cold redundancy is proposed to be used. This can be explained by the model assignment and usage: the model should determine the number of backup components necessary for maintenance.

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