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Modeling of the Cement Unloading Process with the Queuing Theory and Optimization of its Parameters

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Abstract: The stuyd considers the problems arising in the process of unloading cement with vehicles on the example of OAO "Tyumenskaya Domostroitelnaya Kompaniya". Modeling of the main parameters of the cement unloading system based on the Queuing theory has been performed. Functional relationships between the mean vehicle queuing time, the number of silos and vehicle unloading time have been built. It has been shown that with the number of silos equal to three the vehicle queue will continuously grow. The reason for this reduction of service channels is emergency shutdowns caused by equipment failure. As the operating experience shows transitions of metal pipes are mostly exposed to development of fatigue cracks. To identify the most probable locations of crack occurrence it has been suggested to use original means of registration of cyclic damage in metal such as the Integral Strain Gauge (ISG). Under strain cycling the gauge material changes its physical properties and a reaction in the form of dark spots occurs on its surface. The previously performed studies have shown that the form of the ISG reaction corresponds to the pattern of compression strain distribution. To coordinate the calculated and experimental data the ANSYS finite element package has been used in this study which allows evaluating the stress-strain state of a part. To evaluate the ISG reaction a special macros (script) in the APDL language has been developed.

Key words: Cement, unloading, queue, the Queuing theory, fatigue crack, finite element method, integral strain gauge

INTRODUCTION

Cement is one of the key construction materials used for concrete production, wall covering, floor screed and other purposes. It has such important properties as frost resistance, strength and high density, allowing it to be used both independently and as a component of many materials. The scope of its use is so wide that it is difficult to find a field of construction where this material would not be in demand (Loganina *et al*., 2016).

Transportation of cement is a major part of construction activity. It is necessary to meet the requirements for the safety of this expensive material. As a result of dispersal a loss of cement reaches from 5-10 % during transportation and cargo handling operation using non-specialized transport vehicles. Cement dust is harmful to humans and it is required to transport it in closed, sealed cement bulk trucks. Cement is loaded with the use of vacuum created by a special compressor in the truck tank. It is unloaded mechanically by means of an auger driven by rotation of the vehicle power take-off device or pneumatically by means of a specially installed compressor. The advantages of this method are: comparative efficiency, significant amounts and work safety (Farzi, 2007).

MODELING OF THE CEMENT UNLOADING PROCESS BASED ON THE QUEUING THEORY (QT)

The Queuing theory is entirely based on the theory of probability and mathematical statistics. To a certain extent it is connected with poisson distribution that describes the probability of the number of occurrences of any event in a given time interval. The goal of the Queuing theory is to develop recommendations for rational building of a Queuing System (QS), its operation management and regulation of request flows to ensure high efficiency of the entire system (Azadeh *et al*., 2015; Lantz and Rosen, 2017).

QSs play an important role in many production fields, consumer services and special type economics and finance. Each system includes a certain number of servicing devices or servicing channels. Service requests in the QS come one after another at random moments of time. Maintenance of a request lasts for some time, after which the channel is released and is ready to receive the next request. Each system, depending on a number of channels and their performance has a capacity that allows it to successfully cope with the request flow. Therefore, the subject of the Queuing theory is building a

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mathematical model that allows calculating QS parameters for its efficient operation (Vikitset and Ruangkanjanases, 2016; Zhou and Liu, 2017).

We consider a practical example using the OAO "Tyumenskaya Domostroitelnaya Kompaniya" experimental data, namely an example of unloading cement trucks at a cement stock with four silos (n = 4). In this case, we are dealing with a four channel QS with a queue of ten vehicles (i.e., m = 10). The mean vehicle entrance rate is • = 4 (vehicle/h) and the mean unloading time of one truck is (h/vehicle). Then we can determine the unloading rate:

$$\mu = \frac{1}{t_u} = \frac{1}{0.825} = 1.212(\text{vehicle/hour}) \quad (1)$$

Loading rate:

$$p = \frac{\lambda}{\mu} = \lambda \cdot t_u = 4.0.825 = 3.3 \quad (2)$$

Next, we define if the request list will grow infinitely under the condition given in the study (Fernandez-Segovia *et al*., 2006):

$$\frac{p}{n} = \frac{3.3}{4} < 0.825 \quad (3)$$

Accordingly, the QS will have the state when there will be no requests and $p_0 > 0$. In study of Pourvaziri and Pierreval (2017) a method of building a state graph for the system under study an algorithm of probability calculation when all the silos are free and the probability of a queue and the mean vehicle queuing time are given.

State graph of the studied QS under study is shown in Fig. 1. We calculate probability p_0 when all the silos are free:

$$p_0 = \left(1 + \frac{p}{1!} + \frac{p}{2!} + \frac{p}{3!} + \frac{p^{n+1}}{n!(n-p)}\right)^{-1} = 0.023 \quad (4)$$

Based on the calculation we find that on average all the silos will stand idle during 2% of the total time. We define state probabilities (queue probability):

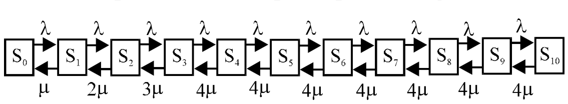

Fig. 1: QS state graph (•-entrance rate, μ-unloading rate)

$$p_5 = \frac{p^{n+1}\cdot p_0}{n!(n-p)}\cdot p_0 \frac{3.3^{4+1}}{4!(4-3.3)}\cdot 0.023 = 0.53 \quad (5)$$

Next, we calculate the number of vehicles in the queue:

$$L_q = \frac{p^{n+1}\cdot p_0}{n.n!}\cdot\left(1-\frac{p}{n}\right)^{-2} = 3.027 \quad (6)$$

Mean vehicle queuing time is defined by the little formula (Hajipour *et al*., 2016):

$$t_q = \frac{1}{\lambda}\cdot L_q = \frac{1}{4}\cdot 3.027 = 0.757\ (\text{h}) \quad (7)$$

To sum up:

- The "idleness" probability of all the silos is on average 2% of work time
- The probability to get in queue for a vehicle is 53%
- The mean number of vehicles in a queue for unloading is 3
- The mean vehicle queuing time is about 45 min

The obtained parameters are not satisfactory, since, a high probability of a cement truck queue slows down the technological process and also affects the performance of a cement stock in general. The results of the study of a four-channel QS with different unloading time for one vehicle and a different vehicle entrance rate is presented in Table 1.

The comparison of the obtained data (in green) with the source data (in orange) allows making a conclusion that the shortest queue can be achieved by replacing the old compressor with a more powerful one or by increasing the diameter of the silos openings. Also, the table shows that the installation of new equipment will reduce the queuing time 13 times (42 min). For a more accurate analysis of our system, we try to model a situation when the number of operating silos is different from the source one.

We suppose that the production re-arrangement will result in an installation of a new mount for unloading cement into a silo. Then, the number of operating silos (n = 5). The obtained parameters of a five-channel QS are summarized in Table 2.

Based on the obtained data (in green), we can conclude that the increase in the number of operating silos has resulted in a reduction of the queue, reduction of the queue probability from 53-20% and nearly five-fold reduction (36 min) of the vehicle queuing time.

Table 1: Parameters of a four-channel QS

---------Initial parameters-------			μ	p	k_p	p_0	p_5	L_q	t_q
	t_u = 0.925	• = 3	1.081	2.775	0.694	0.052	0.291	0.949	0.316
n = 4		• = 4		3.7	0.925	0.008	0.776	10.347	2.587
		• = 5		4.625	1.156	-	-	-	-
		• = 6		5.55	1.388	-	-	-	-
	t_u = 0.825	• = 3	1.212	2.475	0.619	0.076	0.193	0.506	0.169
		• = 4		3.3	0.825	0.023	0.53	3.027	0.757
		• = 5		4.125	1.031	-	-	-	-
		• = 6		4.95	1.238	-	-	-	-
	t_u = 0.725	• = 3	1.379	2.175	0.544	0.108	0.12	0.262	0.087
		• = 4		2.9	0.725	0.044	0.339	1.234	0.309
		• = 5		3.625	0.906	0.01	0.725	7.738	1.548
		• = 6		4.35	1.087	-	-	-	-
	t_u = 0.625	• = 3	1.6	1.875	0.469	0.149	0.068	0.128	0.043
		• = 4		2.5	0.625	0.074	0.2	0.533	0.133
		• = 5		3.125	0.781	0.031	0.44	2.011	0.402
		• = 6		3.75	0.938	0.006	0.811	12.975	2.163
	t_u = 0.525	• = 3	1.905	1.575	0.394	0.205	0.034	0.056	0.019
		• = 4		2.1	0.525	0.117	0.105	0.22	0.055
		• = 5		2.625	0.656	0.063	0.238	0.694	0.139
		• = 6		3.15	0.788	0.03	0.452	2.128	0.355

Where n-number of channels (operating silos): t_u-the mean unloading time of one truck; • -entrance rate; μ-unloading rate, p-loading rate; P_0-probability when all the silos are free; p_5-probability when all the silos are occupied; L_q-number of vehicles in the queue and t_q-vehicle queuing time

Table 2: Parameters of a five-channel QS

---------Initial parameters------			μ	p	k_p	p_0	p_5	L_q	t_q
	t_u = 0.925	• = 3	1.081	2.775	0.555	0.06	0.102	00.23	00.077
		• = 4		3.7	0.74	0.02	0.329	01.265	00.316
		• = 5		4.625	0.925	0.003	0.758	10.104	02.021
		• = 6		5.55	1.11	-	-	-	-
	t_u = 0.825	• = 3	1.212	2.475	0.495	0.082	0.062	00.124	00.041
		• = 4		3.3	0.66	0.033	0.209	00.615	00.154
n = 5		• = 5		4.125	0.825	0.011	0.498	02.844	00.569
		• = 6		4.95	0.99	0.0003	0.965	96.528	16.08
	t_u = 0.725	• = 3	1.379	2.175	0.435	0.112	0.035	00.062	00.021
		• = 4		2.9	0.58	0.052	0.123	00.293	00.073
		• = 5		3.625	0.725	0.022	0.304	01.104	00.221
		• = 6		4.35	0.87	0.006	0.606	04.663	00.777
	t_u = 0.625	• = 3	1.6	1.875	0.375	0.153	0.018	00.028	00.009
		• = 4		2.5	0.5	0.08	0.065	00.13	00.033
		• = 5		3.125	0.625	0.041	0.168	00.447	00.089
		• = 6		3.75	0.75	0.019	0.346	01.385	00.231
	t_u = 0.525	• = 3	1.905	1.575	0.315	0.207	0.007	00.011	00.003
		• = 4		2.1	0.42	0.121	0.03	00.052	00.013
		• = 5		2.625	0.525	0.07	0.081	00.17	00.034
		• = 6		3.15	0.63	0.039	0.173	00.468	00.078

Where n-number of channels (operating silos): t_u-the mean unloading time of one truck ; • -entrance rate; μ-unloading rate; p-loading rate; P_0-probability when all the silos are free; p_5-probability when all the silos are occupied; L_q-number of vehicles in the queue and t_q-vehicle queuing time

We assume that there is no way to unload cement into one of the silos as a result of a fatigue crack in the equipment pipe. Figure 2 shows a crack in a metal pipe which has led to a material dispersal and shutdown of one of the silos.

Then the number of operating silos (n = 3). The obtained parameters of a three-channel QS are summarized in Table 3. Based on the obtained data (in orange) it can be stated that the reduction of operating silos has led to increasing the queue and 100% occurrence of queue probability. Figure 3 shows the relationship between the mean vehicle queuing time and the time of unloading every vehicle.

METHOD OF PREVENTING EMERGENCY SHUTDOWNS

The study has analyzed the queuing system on the example of unloading cement trucks at a cement stock using four silos. It has shown that the most undesirable situation is a reduction of operating silos usually caused by equipment failure due to the occurrence of cracks in metal tubes.

The most effective solution could be a prevention of emergency shutdowns occurring in the process of cement pneumatic transportation. A crack in a metal pipe leads to cement dispersal and consequently, to a loss of material

Table 3: Parameters of a three-channel QS

........Initial parameters.......			μ	p	k_p	p_0	p_5	L_q	t_q
	t_u = 0.925	• = 3	1.081	2.775	0.925	0.018	0.797	10.627	3.542
		• = 4		3.7	1.233	-	-	-	-
	t_u = 0.825	• = 3	1.212	2.475	0.825	0.048	0.568	3.245	1.082
n = 53		• = 4		3.3	1.1	-	-	-	-
	t_u = 0.725	• = 3	1.379	2.175	0.725	0.085	0.384	1.396	0.465
		• = 4		2.9	0.967	0.007	0.906	27.193	6.798
		• = 5		3.625	1.208	-	-	-	-
	t_u = 0.625	• = 3	1.6	1.875	0.625	0.132	0.242	0.646	0.215
		• = 4		2.5	0.833	0.045	0.585	3.511	0.878
		• = 5		3.125	1.042	-	-	-	-
	t_u = 0.525	• = 3	1.905	1.575	0.525	0.193	0.139	0.292	0.097
		• = 4		2.1	0.7	0.096	0.345	1.149	0.287
		• = 5		2.625	0.875	0.032	0.677	5.413	1.083
		• = 6		3.15	1.05	-	-	-	-

Where n - number of channels (operating silos): t_u-the mean unloading time of one truck; • -entrance rate; μ-unloading rate; p-loading rate; P_0-probability when all the silos are free; p_5-probability when all the silos are occupied; L_q -number of vehicles in the queue and t_q-vehicle queuing time

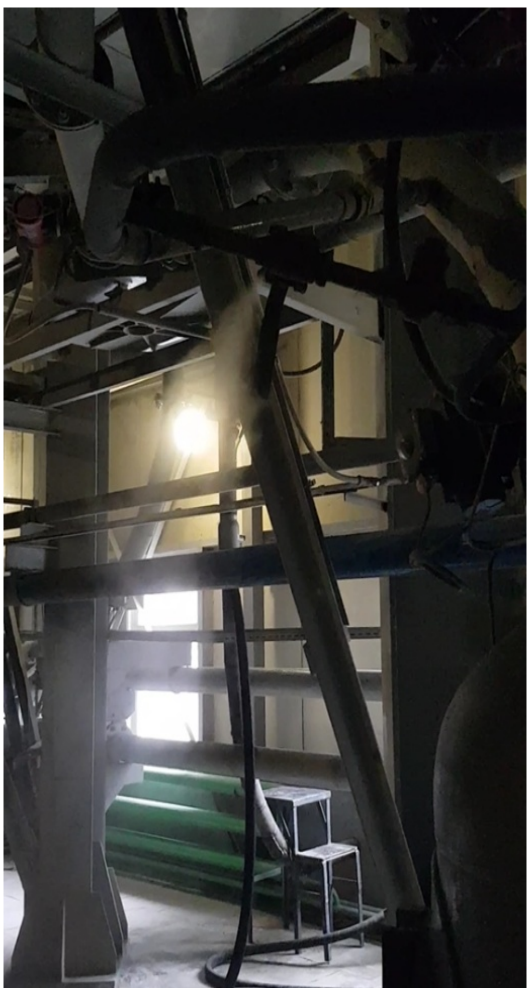

Fig. 2: Crack in a metal pipe

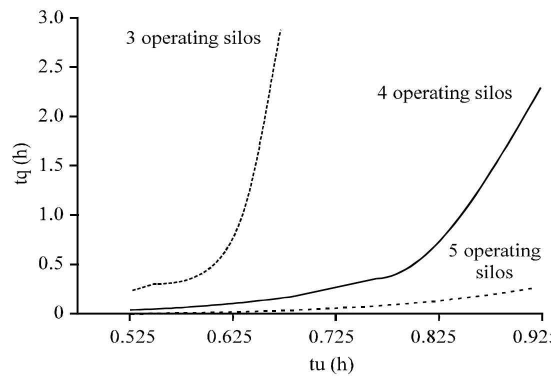

Fig. 3: Relationship between the mean vehicle queuing time and the time of unloading every vehicle

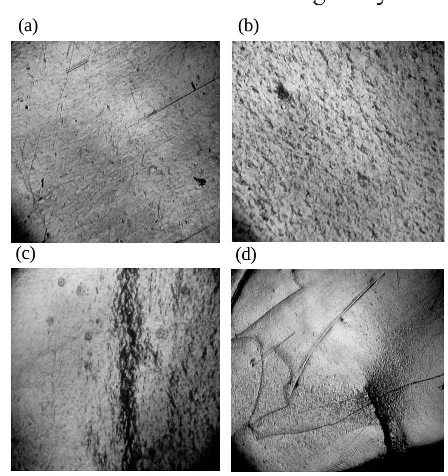

Fig. 4: Examples of reaction of ISG, placed on different machine parts

and worsening of working conditions for employees. It is possible to predict the occurrence of fatigue cracks with fatigue indicators (Syzrantsev and Syzrantseva, 2016). One of the most promising representatives of this class of gauges is the Integral Strain Gauge (ISG) which is a strip of metal foil obtained by a special technology (Syzrantsev and Syzrantseva, 2017). In the process of strain cycling the gauge material properties change and a reaction occurs on its surface in the form of “Dark spots” (Fig. 4).

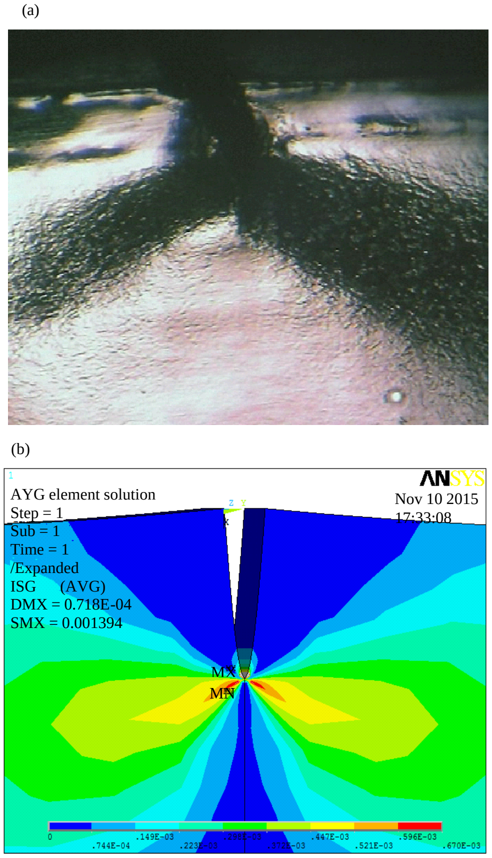

Fig. 5: Decryption the ISG reaction

The moment of their occurrence correlates with the amplitude of stresses and the number of strain cycles of a part.

As shown by Syzrantseva *et al.* (2017), the shape of the first dark spots boundaries on an ISG is similar to the pattern of compression strain on the surface of the part. The evaluation of the stress-strain condition of parts is performed in the ANSYS finite element package (Syzrantseva *et al.*, 2016) and to decrypt the ISG reaction the researchers have developed special macros in the APDL language (Syzrantsev and Syzrantseva, 2016) that enables to visualize the compression strain pattern distribution. Figure 5 a shows a picture of an ISG reaction for a part with a crack and Fig. 5 b shows the result of the described macros work. During the finite element modeling as soon as a loading condition for a pipe has been selected during operation, it becomes possible to determine the fracture mechanics parameters responsible for the crack opening (Fedelich, 1998; Sankararaman *et al.*, 2011). This allows monitoring the most dangerous areas of the pipe to prevent emergency shutdowns.

CONCLUSION

The performed modeling of the cement unloading system has allowed defining the limit parameters of the queuing system and suggesting methods of preventing equipment shutdowns causing unacceptable queues and vehicle idleness during unloading.

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