Using of Weibull Distribution in Diagnostics of Technological Processes

Využití Weibullova rozdělení při diagnostice technologických procesů

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The contribution has been focused on issues of modelling the mechanisms of defaults in various industrial areas. The evaluation problem of a technical condition is complicated and its solution has been significant due to the fundamental reason: defaults mechanisms, i.e.physical, chemical or other processes leading to formation of a default, are enacted through variable speed. The aim is to propose and examine methods for establishing of parameters shape of Weibull distribution of probability random quantity for different malfunction mechanisms with the use of genetic algorithms and to present the given examples from industrial practice. It will be feasible to form diagnosis about current technical condition of objects or their prognosis on the basis of newly-emerged models of individual default mechanisms. Weibull Distribution has been flexible and adaptable to data in a wide spectrum. Time until a default, cycles until a default, transportation distance, mechanical strain or analogous connected parameters have to be recorded with all objects. This concerns an effective modelling – knowledge of behavior of a default in time - decrease of costs for maintenance, decrease of number of device diagnostics, decrease of sudden shutdowns could be achieved and thus it has been a key information for effective technology management, maintenance with bonds to economics and effectiveness of process.

Key words*: Default mechanisms, diagnostics; Weibull distribution; a model; genetic algorithm development*

Příspěvek je zaměřen na problematiku modelování mechanismů poruch v různých průmyslových oblastech. Ve strojích a technických zařízeních při jejich provozu probíhají děje, které mají za následek změny vlastností součástí. Tyto změny jsou prvotními technickými příčinami poruch. Souhrn působících vlivů a dějů se nazývá mechanismus poruch. Vznik poškození lze charakterizovat jako proces, kdy při přibližování povrchů se porušuje adsorpční i oxidová vrstva, na materiál působí okolní prostředí, materiály se dostávají do přímého kontaktu. Probíhají elektrochemické reakce, vznikají mikrospoje, které se v důsledku vzájemného pohybu rozrušují a dochází k oddělování částic materiálu. Intenzita těchto procesů závisí zejména na: druhu a vlastnostech prostředí a vzájemně na sebe působících povrchů; přítomnosti a vlastnostech média mezi povrchy; charakteristikách relativního pohybu povrchů: směr, rychlost a jejich časové změny; zatížení (velikost působících sil, jejich časové změny). Problém hodnocení technického stavu je složitý a jeho řešení je přitom nezbytné z tohoto základního důvodu: mechanismy poruch, tj. fyzikální, chemické nebo jiné procesy vedoucí ke vzniku poruchy, probíhají proměnlivou rychlostí. Cílem je navrhnout a ověřit metodiku pro stanovení paramentu tvaru Weibullova rozdělení pravděpodobnosti náhodné veličiny pro různé mechanismy poruch s využitím genetických algoritmů a danou metodiku prezentovat na daných příkladech z průmyslové praxe. Na základě takto vzniklých modelů jednotlivých mechanismů poruch bude možno vytvářet diagnózy o aktuálním technickém stavu objektu nebo jeho prognózu. Weibullovo rozdělení je pružné a přizpůsobivé pro data v širokém rozsahu. U všech objektů je třeba zaznamenávat dobu do poruchy, cykly do poruchy, přepravní vzdálenost, mechanické namáhání nebo obdobné spojité parametry. Jedná se o efektivní modelování - znalost chování poruchy v čase – tímto se dosáhne snížení nákladů na údržbu, snížení počtu diagnostik zařízení, snížení počtu náhlých odstávek a tedy je klíčovou informací pro efektivní řízení technologie, údržby s vazbou na ekonomiku a efektivnost procesu.

Klíčová slova*: Mechanismy poruch; diagnostika; Weibullovo rozdělení; model; genetický algoritmus*

The problem of evaluation of technical condition has been complicated and nevertheless, its solution has been essential due to the fundamental reason: default mechanisms, i.e. physical, chemical or other processes leading to forming of defaults, are enacted with changeable speed. This implies that external demonstration of the default mechanisms – defects of functional surfaces has been changed in time quantitatively with different speed, which stands for various elements of the same system, for the same elements of various systems, as well as for the same element in different periods of its operation. There have been a few causes. The most serious has been construction, production and operation influences.

Variability in the speed of development of default mechanisms causes that in a given moment it is not possible to state the level of the technical condition without necessary source information. Moreover, the problem is the level (i.e. the ability of an object to perform required

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functions in a given moment), which must be evaluated with the limited quality of gained information.

1. Damage – Reasons for Maintenance

Formation of failures and interruption of a run of machines has been caused by a number of influences and processes, which affect machines not only while they work. Consequently, the influences have been responsible for changes of functional qualities of parts of machines and this was the primary technical cause of failures – damages [1].

As for the form, wearing out and overload have been distinguished.

Wearing out can be divided into mechanical wearing out (abrasion), corrosion, fatigue, and ageing that represent the most important types of damage. It is not possible to prevent it even in the course of normal operation. The cause of overload can be a wrong use of machines or development of wearing out. The overload can lead either straight to the damage or to an accelerated wearing out [1].

As for mechanical basic elements of machines and devices, there have been the following default mechanisms:

- wearing out;
- corrosion;
- material fatigue;
- material ageing;
- influence of external mechanical forces;
- thermal degradation of the material.

Electronic and electromechanical elements cover the following default mechanisms:

- interruption
- short circuit, sparkle, flashovers
- change of parameters
- fouling.

The stated default mechanisms have their external displays, which characterize external changes of basic elements. The term „defect of machine part“ or Czech equivalent „damage“ has been used for a long time in connection with mechanical elements. Functional surfaces of basic elements cover the most serious defects:

- wearing out;
- corrosion;
- imprint;
- deformation;
- break;
- rift.

2. Algorithm Development of Defining Parameters of Weibull Distribution Depending on Default Mechanisms

Different systems of maintenance can be distinguished from the point of choice of time moment [2]. Let us assume it is possible to gain corresponding figures of physical life for individual elements of technical devices (based on analysis and collecting data about reliability) [2]. Furthermore, let us assume we could observe continuously changes in the technical condition of the stated elements with various diagnostic signals (time of usage, operation time, diagnostic and structural parameters), and with the help of various diagnostic methods, appliances and registration devices (Fig. 1). Circles in the graph represent physical marginal states (defaults), at the same time their coordinates are given by corresponding diagnostic signal and their physical life, e.g. S_1 and t_1.

Some steps for detection of point estimation for parameters of the Weibull distribution have been followed [3]:

a) Analysis of input statistical sample of diagnostic data,
b) Elimination of statistically extreme values
c) Transformation of data into relative values according to the character of the data
d) Expression of distribution function or trouble-free function of the Weibull distribution of probability according to the character of data
e) Establishing of complex criterion (purpose function) for optimization of parameters
f) optimization of parameters of Weibull distribution with the use of evolutionary methods.

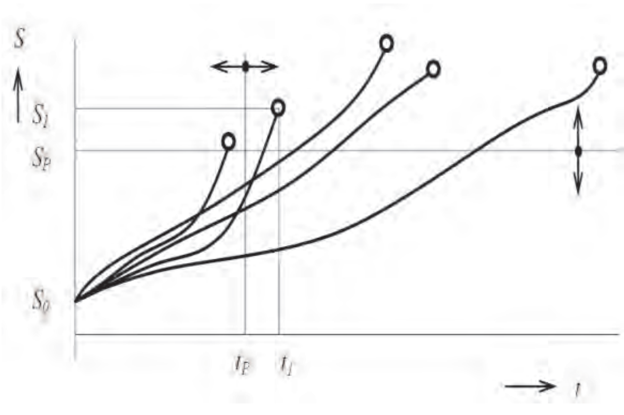

Fig. 1 Illustration of structural diagnostic signals. Source: [1]
Obr. 1 Ukázka strukturálních diagnostických signálů. Zdroj: [1]

The whole algorithm development for establishing parameters of the Weibull distribution of default mechanisms is illustrated in Fig. 2.

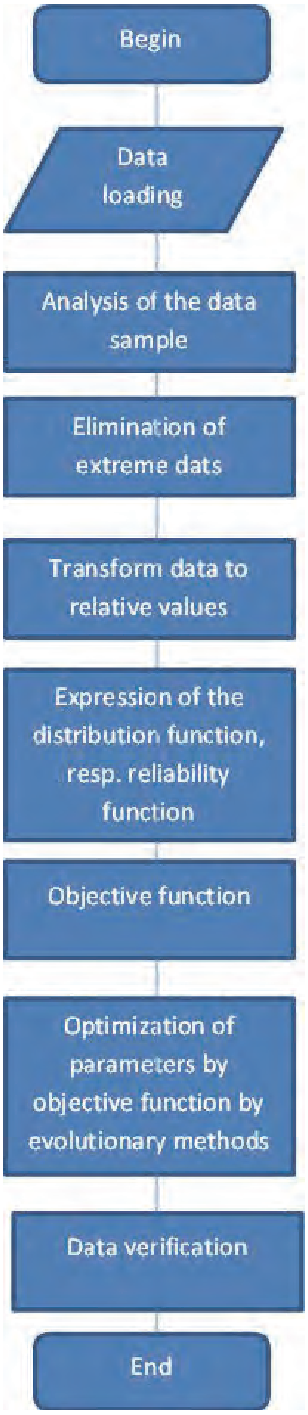

Fig. 2 Algorithm. Source: our own data
Obr. 2 Algoritmus. Zdroj: vlastní údaje

Determination models wear is problem of optimization. Its solution can be divided into three main parts.

The first part consists of reading the input data and performing a statistical analysis of these data. Within this analysis using statistical tests, eg. are eliminated extreme data, established span and other important statistics.

The second part is the determination of the purpose function. The purpose function is determined by the nature of the input data. The following variants of the purpose function are used to solve this problem

$$\left(\frac{\sum_{i=1}^{n} t_i^{\beta}}{n}\right)^{\frac{1}{\beta}} = \eta \qquad \frac{\sum_{i=1}^{n}(t_i^{\beta}\ln(t_i)}{\sum_{i=1}^{n} t_i^{\beta}} - \frac{1}{\beta} - \frac{1}{n}\sum_{i=1}^{n}\ln t_i = 0 \tag{1}$$

$$\left(\frac{\sum_{i=1}^{r} t_i^{\beta} + (n-r)t_r^{\beta}}{r}\right)^{\frac{1}{\beta}} = \eta \qquad \frac{\sum_{i=1}^{r}(t_i^{\beta}\ln(t_i) + (n-r)t_r^{\beta}\ln(t_r)}{\sum_{i=1}^{r} t_i^{\beta} + (n-r)t_r^{\beta}} - \frac{1}{\beta} - \frac{1}{r}\sum_{i=1}^{r}\ln t_i = 0 \tag{2}$$

$$\left(\frac{\sum_{i=1}^{r} t_i^{\beta} + (n-r)T^{\beta}}{r}\right)^{\frac{1}{\beta}} = \eta \qquad \frac{\sum_{i=1}^{r}(t_i^{\beta}\ln(t_i) + (n-r)T^{\beta}\ln(T)}{\sum_{i=1}^{r} t_i^{\beta} + (n-r)T^{\beta}} - \frac{1}{\beta} - \frac{1}{r}\sum_{i=1}^{r}\ln t_i = 0 \tag{3}$$

Where t_i – input data, β, η - Weibull's distribution parameters, n - number of values, r - number of failures until the time of monitoring, t_r - time to r-th failure, T - monitoring time.

The third part is the implementation of the optimization process itself, which is solved by the evolutionary algorithm. The evolutionary algorithm is a method of artificial intelligence, which represents a robust optimization method. The basis of the solution is the transformation of the purpose function into the fitness function, according to which the suitability of the individual strings is considered as a solution to the optimization and delineation of the searched space.

For the application of algorithm development four processes with different types of degradation mechanisms have been selected – atmospheric corrosion, abrasive wearing out, creep and electrotechnical process with the change of parameters.

3. Application of Algorithm Development on Selected Industrial Uses

The first process consists of examinations of atmospheric corrosion of metal materials. The process has been widely spread since nearly all products, machines, equipment, constructions, etc., are exposed to outer atmospheric conditions, to the negative influence of the environment – air pollution, rainfalls, humidity, sunshine, etc.

Within solution, three samples of data from the process involving atmospheric corrosion were used.

The compares of the actual and model data of the process with atmospheric corrosion is in table 2.

In the first two columns, there are sharp data, which were analyzed and examined for extreme deflections.

The third column is a model of corrosion loss expressed in the form of relative values due to their increasing character. The distribution function of a two-parametric Weibull division of probability [4] serves as a model of Weibull distribution.

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Tab. 1 Calculated parameters of atmospheric corrosion degradation model. Source: our own data
Tab. 1 Vypočtené parametry modelu degradace atmosférické koroze. Zdroj: vlastní údaje

Parametres WR	η = 0.3611	β = 0.885

Tab. 2 Comparison of the measured and calculated model of degradation with atmospheric corrosion. Source: our own data
Tab. 2 Srovnání naměřeného a vypočteného modelu degradace s atmosférickou korozí. Zdroj: vlastní údaje

Exposition time year	Corrosion loss	Model 1	Model W	Deflection	Model corrosion loss
1	204.9	0.35321	0.30312	0.00251	175.839
1	154.7	0.26668	0.30312	0.00133	175.839
1	206.8	0.35649	0.30312	0.00285	175.839
1	224	0.38614	0.30312	0.00689	175.839
1	153	0.26375	0.30312	0.00155	175.839
1	148	0.25513	0.30312	0.00230	175.839
2	257.2	0.44337	0.48672	0.00188	282.349
2	252.9	0.43596	0.48672	0.00258	282.349
2	334.9	0.57731	0.48672	0.00821	282.349
3	314.9	0.54284	0.61513	0.00523	356.835
3	323.5	0.55766	0.61513	0.00330	356.835
3	380.3	0.65558	0.61513	0.00164	356.835
5	442.7	0.76314	0.77701	0.00019	450.741
5	471.6	0.81296	0.77701	0.00129	450.741
10	580.1	1.00000	0.93742	0.00392	543.797
			criterion	0.0457	

The columns „Model W“ and „Deflection“ present parametres of the Weibull distribution with the help of purpose function (criterion cell and evolutionary methods (Fig. 3), which is minimized.

The column „Model corrosion loss“ expresses a model with stated parametres of the Weibull distribution used for verification of the model.

The above-stated models establish the shape parameter of the Weibull distribution of process models, where the default mechanism was atmospheric corrosion, reaching the values 1.1080, 0.9253 and 0.885. The average value was 0.9727 and average deflection was 0.0901.

The second examined process was wearing out of inserts of crystallization tools. It has been stated that the shape parameter of the Weibull distribution of the process models, where the value of abrasive wearing out was 0.7209. The parameter was obtained from measurements of five inserts of a crystallization tool [5].

The third process covered the field of energetics, and the process of degradation of steam piping was analyzed. The shape parameter of distribution of models of steam piping degradation had the value of the speed of flow 4.0786 and the parameter for entire deformation – the value 2.7439.

The last analyzed process was in the field of electrotechnology – specifically degradation of accumulator batteries. It was established that the shape parameter of the Weibull distribution of degradation models of accumulator batteries while assuming default mechanisms – change of the parameter, discharging speed, had the value 0.5719.

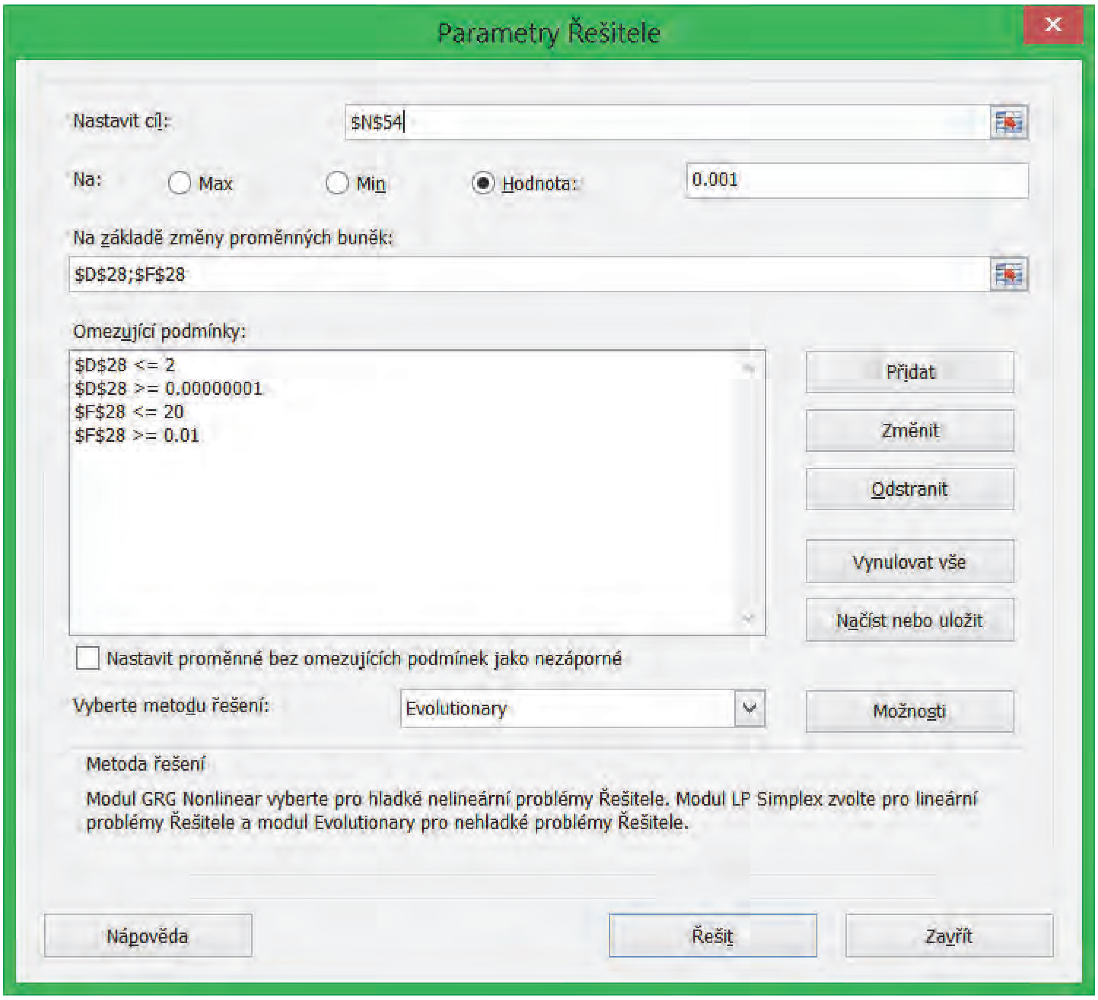

Fig. 3 Adjustment of parameters of evolutionary methods used in the course of atmospheric corrosion. Source: our own data
Obr. 3 Přizpůsobení parametrů vývojových metod užitých v průběhu atmosférické koroze. Zdroj: vlastní údaje

Conclusions

Effective modeling of processes of default mechanisms enables the knowledge of the behavior of time defaults and in technical practice it should serve to reduce the number of diagnostics of appliances, to reduce the number of sudden shutdowns and thus it has been a key information for effective technology operation, maintenance binding economics, and effectiveness of a process.

Suggested methods were verified on four different processes in the field of metallurgy, energetics, and electrotechnology with successful results.

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