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Toward the Criterion of Erosion Threat of Steam Turbines Blading Through the Structure of the Droplet Stream

Nomenclature

a – constant [m/s],
c – velocity in the aerodynamic wake behind the stator blade [m/s],
c_1 – steam velocity behind the stator blade [m/s],
c_{1ax} – axial component of c_1 [m/s],
c_* – droplet velocity [m/s],
E_k – kinetic energy flux over the surface of the blade,
$f_z(r_*)$, $f_v(r_*)$ – number and volume distribution functions respectively [1/m],
$F' \equiv S_{1k} c_{1ax} \rho_1 (1-x) \frac{y(l/l_w)}{y_{sr}} \frac{z_k}{z_w}$, $\left[\frac{\text{kg}}{\text{ms}}\right]$,
$m(r_*)$ – mass of all droplets of radius r_* [kg],
$m_M = m(r_M)$ – mass of all modal droplets [kg],
$M_{c1} = c_1/a$ – Mach number,
N_e – normalized erosion resistance [1]
r_{max}, r_{*min} – max. resp. min. droplet radius [m],
r_* – droplet radius [m],
$r_*(\eta)$ – see Fig. 5 [m],
$Re_{cl} = c_1 l/\nu$ – Reynolds number,
R – distance from turbine axis [m],
ΔR_1 – finite element of R [m],
S_{1k} – characteristic dimension of the stator blade, see Fig. 7 [m],
t_w – rotor blade spacing [m],
$U_a(\eta)$ – total amount of water impinging the unit blade surface element per unit time [kg/m²·s],
$U_{eM}(\eta)$ – maximum instantaneous value of the volume of material loss per unit area, per unit time [m/s],
w_*, w_{*ax}, w_{*N} – droplet velocity in relative reference frame, its axial and normal to the blade surface element, component, see Fig. 5 [m/s],
We, We_{kr} – Weber number and its critical value,
$1-x$, y – moisture fraction,
Y – mean erosion depth [m],
z_k, z_w – number of guide vanes and rotor blades, resp.,
$\beta_{b1}(\eta)$ – blade tangent inclination, see Fig. 5 [dgr],
δM_* – water flow associated with the droplet group radius r_*, and blade surface element [kg/s],
ΔM_* – total amount of water entering the rotor channel of the length ΔR_1 [kg/s],
η, $d\eta$ – co-ordinate and its element, see Fig. 5,
σ – surface tension [kg/s²],
τ – time [s],

1. Introduction

The increase of dimensions of steam turbine final stages has necessitated recently a return to the problems of erosion of the blading in these stages. Consequently variety of new criteria allowing estimation of the erosion threat of the blading has been established.

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A survey of these criteria was presented among others in [1, 2, 3], their advantages as well as shortcomings having been pointed out. Majority of the criteria mentioned was based on new experimental data acquired when operating modern steam turbines of great output; some were based also on a more detailed description of the phenomena leading to erosion. This concerns in particular those criteria that were based on the description of the secondary droplet motion within the axial gap and its collisions with rotor blades. Such criterion, among others, was presented in [4] and [1], whereas in [5] new experimental data supporting it were specified. In the papers mentioned a hypothesis has been used that the maximum erosion rate is proportional to certain power of the normal component of the impact velocity as well as to the amount of water impinging the unit blade surface element per unit time. The same hypothesis has been also applied in e.g. [6, 7]. The normal component of the impact velocity was estimated in [1, 4, 5], the estimation having been based on the analysis of the motion of those individual water droplets that have their trajectories tangent to the leading edge of the neighbouring rotor blade. In such a way the largest droplets were selected from all those impinging the rotor blade surface element under consideration [4]. The amount of water was evaluated approximately. It was also assumed when formulating the criterion mentioned that primary droplet generation caused by spontaneous condensation as well as the course of droplet settling on guide vanes, and also generation of the secondary droplets are in modern turbines similar. This assumption was also understood as an approximate one.

The structure of the droplet stream generated at the guide vane trailing edges affects however considerably, as was already shown in [8] and [9], the conditions of droplet impact with a rotor blade. The present paper constitutes an attempt to describe the structure of the secondary droplet stream and to link it with the conditions of steam expansion in a turbine. These data serve as a basis for computation of selected collision parameters. The procedure presented in [8] and [9] is applied. A novel form of a criterion of erosion threat is also proposed basing on this model. It allows to examine the influence of such important design parameters as e.g. the outlet velocity from the of guide vanes apparatus or the axial clearance of a stage and others.

2. Secondary droplets generation in the aerodynamic wake

Recently considerable effort was devoted to the description of the motion of the droplet stream in the aerodynamic wake and its structure [4, 10, 11, 12, 13, 14, 15].

Theoretical parts of these works dealt, in general, with the solution of the equation of droplet motion in the wake, the determination of the slip velocity, the estimation of the region where a droplet ceases to exist as a stable sphere and starts oscillating; also the period necessary to make a given number of oscillations and the point of droplet disintegration were being determined [4, 10, 12]. The above material together with appropriate experimental investigations can serve as a basis for the determination of the size of a largest droplet encountered in the stream and the critical value of the Weber number based upon the droplet slip velocity: $\vec{c}-\vec{c}_*$ [10, 12].

As a result of the works under consideration it came out, among other things, that the process of droplet disintegration ends in a relatively short distance from the trailing edge of the profile producing the wake [4]. Critical values of the Weber numbers determining this distance varied within a wide range from 6÷7 [11] through 10÷14 [16]. This was probably due to the numerous simplifying assumptions made during the calculations (spherical shape of a droplet, duration of oscillations, methods adopted to obtain numerical solutions of the equation of droplet motion, determination of the velocity distribution of the gas in the aerodynamic wake etc.) as well as due to discrepancies of experimental results. Besides, it should be noted that a strict dimensional analysis of the phenomenon under consideration leads to at least 5 dimensionless quantities deciding on its course [12, 15]. Until recently attention was being given only to the relation between the Mach number M_c and the Weber number *We*, none of the remaining similarity criteria having been controlled; this, very likely, did not influence favourably the repeatability of the experimental results.

Insufficiency of the experimental material has induced the idea of basing on a simplified definition of the critical Weber number:

$$We_{kr} = \frac{c_1^2 \, 2r_{*\,\max}\rho_1}{\sigma} . \tag{1}$$

This definition is also more convenient in use than the more refined one based on the droplet slip velocity: $\vec{c} - \vec{c}_*$. The use of the so defined Weber number relates to the suggestion of J. Valha [12, 13] modified by the conclusions resulting from the paper of B. Weigle and H. Severin [14]. It can be shown, namely, that for available investigations of a water film disintegration in a stream of air the critical value of the Weber number We_{kr} is a strong function of the Mach number $M_{c_1} = c_1/a$. Figure 1 shows this relation as based on the results of the investigations of Valha [12, 13] and Weigle and Severin [14]. Consequently, this relation can be used to determine the maximum droplet size.

As it was shown by Valha the structure of a stream of droplets can be described by means of an adequately normalized diagram of a droplet mass distribution function (Fig. 2).

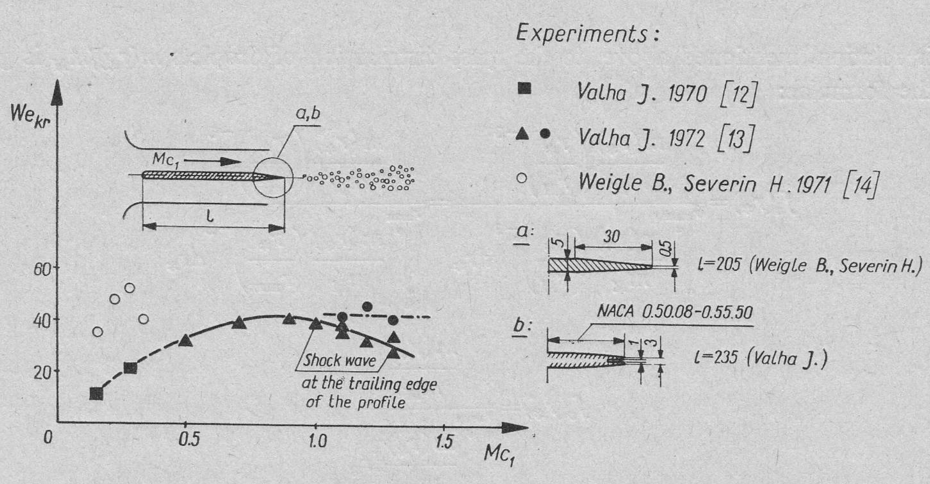

Fig. 1. Critical Weber number for a droplet stream in the aerodynamic wake

This was also confirmed to a certain extent by the investigation of Weigle and Severin. The distribution

$$\frac{m(r_*)}{m_M}=\frac{n(r_*)r_*^3}{n_M r_M^3}$$

which is a function of the relative droplet size r_*/r_{max} is related uniquely to the number and volume distribution functions, $f_n(r_*)$ and $f_v(r_*)$, respectively. The functions, which are used further in this paper (see also e.g. [8, 9, 19]) have been defined as:

$$f_n(r_*)=\frac{n(r_*)}{N}\frac{1}{\Delta r_*}, \qquad f_v(r_*)=\frac{v(r_*)}{V}\frac{1}{\Delta r_*}. \tag{2}$$

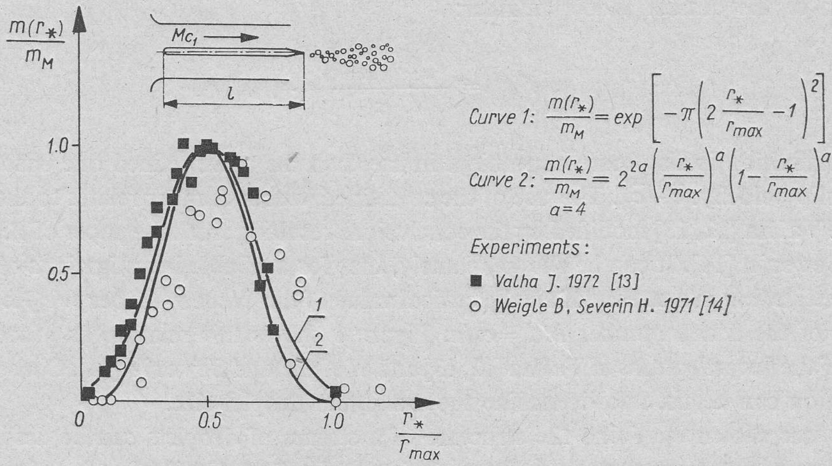

Fig. 2. Mass distribution function of droplet stream

Their relation, mentioned above, to the mass distribution of droplets $m(r_*)/m_M$ is given by the formulae:

$$f_n(r_*)=\frac{\frac{m(r_*)}{m_M}\left(\frac{r_*}{r_M}\right)^{-3}}{\int_0^{r_{max}}\frac{m(r_*)}{m_M}\left(\frac{r_*}{r_M}\right)^{-3}dr_*}=\frac{\frac{m(r_*)}{m_M}\left(\frac{r_*}{r_{max}}\right)^{-3}}{\int_0^{r_{max}}\frac{m(r_*)}{m_M}\left(\frac{r_*}{r_{max}}\right)^{-3}dr_*}, \tag{3}$$

$$f_v(r_*)=\frac{\frac{m(r_*)}{m_M}}{\int_0^{r_{max}}\frac{m(r_*)}{m_M}dr_*} \tag{4}$$

and

$$f_n(r_*)=\frac{\left(\frac{r_*}{r_{max}}\right)^{-3} f_v(r_*)}{\int\limits_0^{r_{max}} \left(\frac{r_*}{r_{max}}\right)^{-3} f_v(r_*)\,dr_*}, \qquad f_v(r_*)=\frac{\left(\frac{r_*}{r_{max}}\right)^{3} f_n(r_*)}{\int\limits_0^{r_{max}} \left(\frac{r_*}{r_{max}}\right)^{3} f_n(r_*)\,dr_*}. \tag{5}$$

Valha assigned [11, 12, 13] the Gaussian function to the normalized distribution function:

$$\frac{m(r_*)}{m_M}=\exp\left[-\pi\left(\frac{r_*}{r_M}-1\right)^2\right]. \tag{6}$$

For r_M he puts:

$$r_M=\sim\frac{1}{2}r_{max}=\frac{1}{4}\frac{We_{kr}\sigma}{c_1^2\rho_1} \tag{7}$$

basing on the investigations carried out by himself. The suggestion was repeated also by Faddiejev [19]. However, disadvantages of employing the Gaussian function (6) for the description of the distribution of $m(r_*)/m_M$ are easy to show. It is namely evident from (6) that for $r_*=0$ and $r_*=r_{max}$ this expression becomes non equal to zero, hence from (3) it comes out that a singularity of $f_n(r_*)$ exists at $r_*=0$. No experimental proof of such properties of the number distribution function exists up to now. Values of f_n and f_v different than zero for $r_*>r_{max}$ are not justified too. A mass distribution function $m(r_*)/m_M$, of such a form that would not lead to the singularities mentioned would constitute a better fit to the results of experiments. A β – function:

$$\frac{m(r_*)}{m_M}=A\left(\frac{r_*}{r_{max}}\right)^a\left(1-\frac{r_*}{r_{max}}\right)^a \tag{8}$$

is, for instance, one of the functions meeting the requirements. It is symmetrical with respect to the $r_*/r_{max}=0.5$ axis and becomes equal to zero at the points $r_*/r_{max}=0$ and 1; the constant A can be determined from the condition:

$$\int\limits_0^{r_{max}} f_n\left[\frac{m(r_*)}{m_M}\right]dr_*=1 \quad \text{or} \quad \int\limits_0^{r_{max}} f_v\left[\frac{m(r_*)}{m_M}\right]dr_*=1\,. \tag{9}$$

No reason of physical nature exists that would prefer the use of other distribution function known from the probability theory, so the formula (8) is adopted in what follows. Figure 2 justifies the adoption of this function as an approximation of the $m(r_*)/m_M$. Distribution functions $f_n(r_*)$ and $f_v(r_*)$ obtained in this way are compared in Figs. 3 and 4 with the results of investigations of B. Weigle and H. Severin [14].

Preliminary character of the assumptions adopted should be emphasized. In particular the difference between the values of We_{kr} as determined in [13] and [14] needs some comment. These differences reach in the range of small M_{c1} numbers up to 100%! There exist many causes of such discrepancies as for instance: different shapes of trailing edges, different levels of flow turbulences, systematic errors depending on the techniques of r_{max} measurements, differences in values of uncontrolled similarity parameters etc. Further investiga-

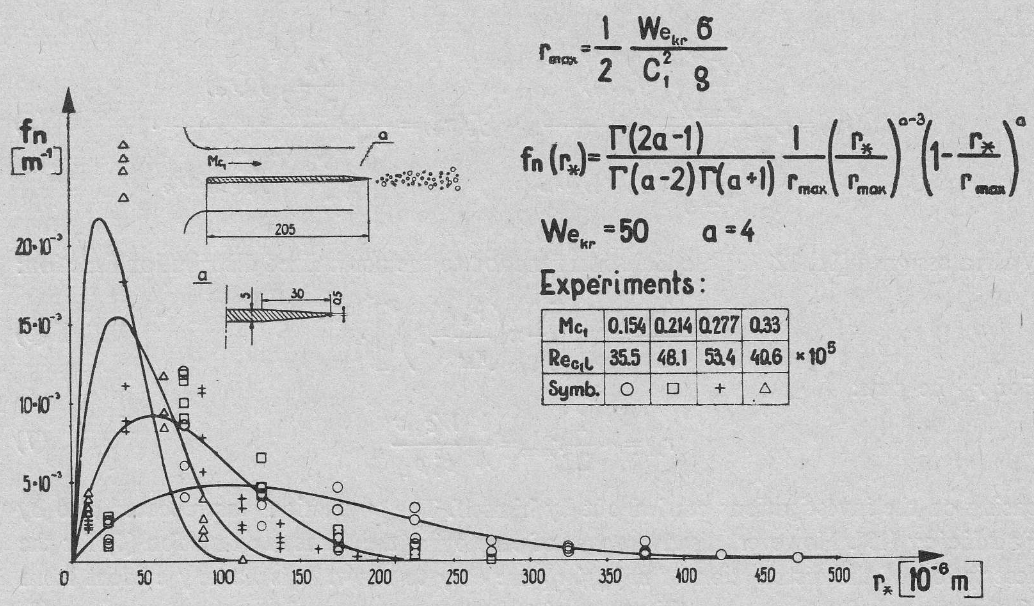

Fig. 3. Number distribution function of droplet stream

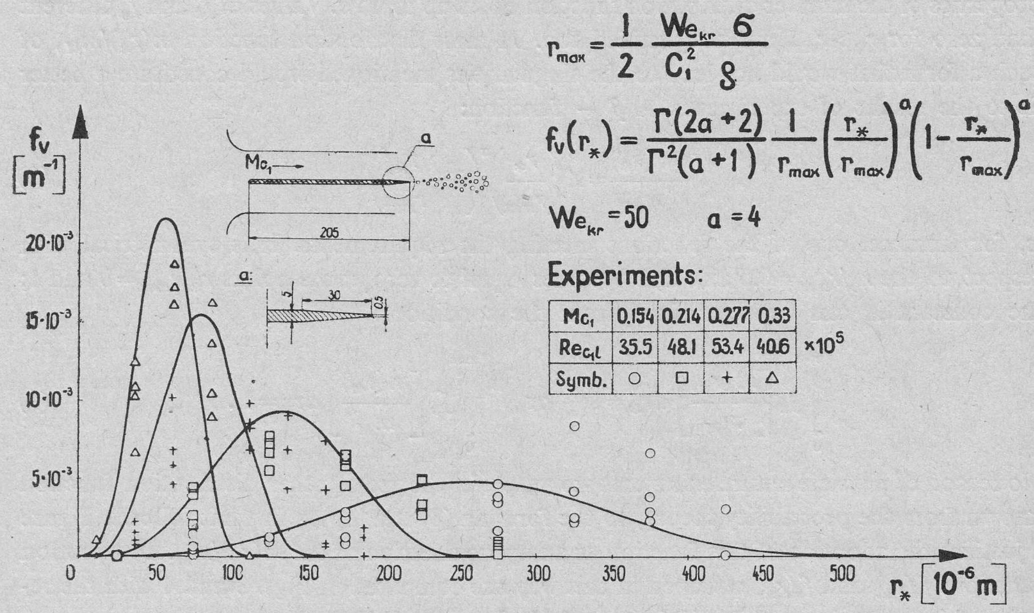

Fig. 4. Volume distribution function of droplet stream

tions designed to explain these differences are being carried out intensely both at the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences and at the University of Michigan [20] within the frames of a common research program.

The description of the droplet stream structure suggested here makes it possible to more closely investigate the conditions of erosion of wet steam turbine blading.

3. Model of secondary droplets collision with the leading edges of rotor blades

The leading edge of a steam turbine rotor blade is eroded due to collisions with slow secondary droplets leaving the guide vanes apparatus of the stage. These droplets seem to be concentrated mostly in the aerodynamic wake* of a guide vane. The motion of the droplets was described in detail in, among others, [1, 4]. It was shown there that the trajectory of a fraction of droplets of a particular size r_* can be determined easily under the assumption that in the limiting case this trajectory is tangent to the leading edge of a next rotor blade (Fig. 5). In [8] and [9] it was shown that an element of a blade surface located by a coordinate η is attacked by droplets having dimensions $r_{*\min} \leqslant r_* \leqslant r_*(\eta)$. These papers presented also a method of calculating such essential collision parameters as:

The amount of water impinging the unit blade surface element per unit time, the element being located by the co-ordinate η:

$$U_a = \frac{\Delta M_*}{\Delta R_1}\frac{1}{t_w}\frac{1}{\int\limits_0^\infty w_{*\mathrm{ax}}(r_*,\eta=0)\,r_*^3 f_n(r_*)\,dr_*}\int\limits_{r_{*\max}}^{r_*(\eta)} w_{*N}(r_*,\eta)\,r_*^3 f_n(r_*)\,dr_* = \frac{\Delta M_*}{\Delta R_1}\,UA(\eta), \quad (10)$$

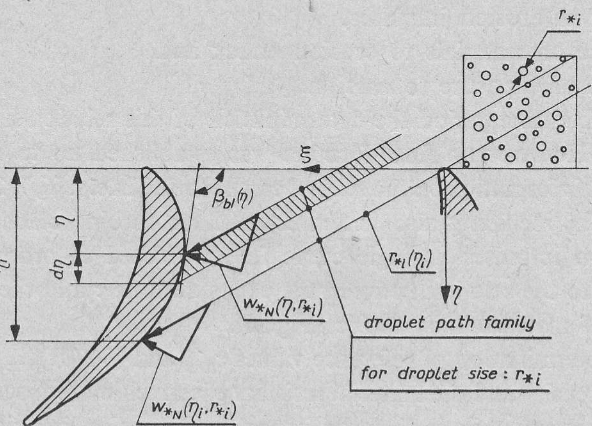

Fig. 5. Kinematics of the secondary droplet motion in the turbine blading axial gap

kinetic energy flux over the unit blade surface due to all droplets impinging this area

$$E_k(\eta) = \frac{\Delta M_*}{\Delta R_1}\frac{1}{t_w}\frac{1}{\int\limits_0^\infty w_{*\mathrm{ax}}(r_*,\eta=0)\,r_*^3 f_n(r_*)\,dr_*}\frac{1}{2}\int\limits_{r_{*\min}}^{r_*(\eta)} w_{*N}^3(r_*,\eta)\,r_*^3 f_n(r_*)\,dr = \frac{\Delta M_*}{\Delta R_1}\,EK(\eta) \quad (11)$$

and many others**.

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* Interesting qualitative investigations pointing out the motion of secondary droplets outside the wake (e.g. [3]) do not provide quantitative data yet.

** An appropriate program for numerical calculations, formulated in the Algol language for a Burroughs B 5500 computer is presented in [8]. Another Algol program for an Odra 1204 computer is available too.

An essential novelty of the described method of calculating parameters of secondary droplets collision with a rotor blade consists in the possibility of taking into account the structure of the droplet stream in the aerodynamic wake of a guide vane. Relating the number of droplets impinging a blade surface element with its location defined by the co-ordinate is another important feature. Attempts to evaluate the number of droplets impinging the blade surface were already made in [21] and [2]. These however were based on a highly simplified computational method. The suggestion to base on the description of the droplet stream structure as presented in the Section 2 is also a considerable progress comparing to the papers [8, 9]. It allows passing from qualitative estimates of [8] and [9] to the more accurate analysis of the blade erosion conditions.

The virtues discussed above give the possibility to formulate a new criterion of erosion threat of turbine blading.

4. Criterion of erosion threat of turbine blading

A rational prediction of erosion effects should be founded on a relation that links together:

- the erosion damage (mean erosion depth Y),
- the intensity of erosion impulses,
- the resistance of materials to erosion attack and
- the duration of exposure to erosion.

For a considerable time period the determination of this relation has been the subject of intense studies. However no final formula was established up to now. An extensive survey of the present information on the subject can be found in e.g. [6, 7, 22]; see also [23,24].

For many metals, including also materials used for turbine blades, and for various intensities of erosion impulses a single curve in normalized co-ordinates was assigned successfully [6, 22] to the relation between the exposure time τ and the time derivative of a linear measure of material loss, $\partial Y/\partial \tau$ (Fig. 6).

However, the determination of reference values τ_{max} and $(\partial Y/\partial \tau)_{max}$ as functions of the erosion impulses intensity and the material resistance is much more troublesome. Usually it is assumed, among other things, that the intensity of erosion impulses is proportional to the product of the amount of water carried onto a unit area of the eroded surface per unit time and certain power of the normal component of the collision velocity. Information on the material resistance to erosion is much more scarce. Attempts to relate this resistance to other mechanical properties of materials did not prove successful yet; at least 6 different opinions on that matter were presented in [22].

Considering all this it appears that the most reasonable solution for the time being is to base on one of those semi-empirical formulae that have acquired enough support in results of experiments. One of such formulae was put forward by Heymann [6, 7, 24]. Using the dimensional analysis and basing on the results of numerous experimental investigations he discovered that the sought relation between the mean erosion depth, the exposure time, material resistance and the intensity of erosion impulses can be expressed by a formula:

$$\tau = Y \frac{\rho_* N_e}{U_a} \left(\frac{2550}{w_{*N}}\right)^5 \exp\left[0.25 (Y/Y_T)\right], \tag{12}$$

where N_e – represents the material resistance to erosion referred to that of chromium-nickel steel, $\frac{1}{\rho_*} U_a \left(\frac{w_{*N}}{2550}\right)^5$ – represents the intensity of erosion impulses, and $\frac{U_a}{\rho_* N_e}\left(\frac{w_{*N}}{2550}\right)^5 = U_{eM}$ – expresses the maximum value of the derivative $\partial Y/\partial\tau$ at the point M on the diagram of Y vs. τ (Fig. 6).

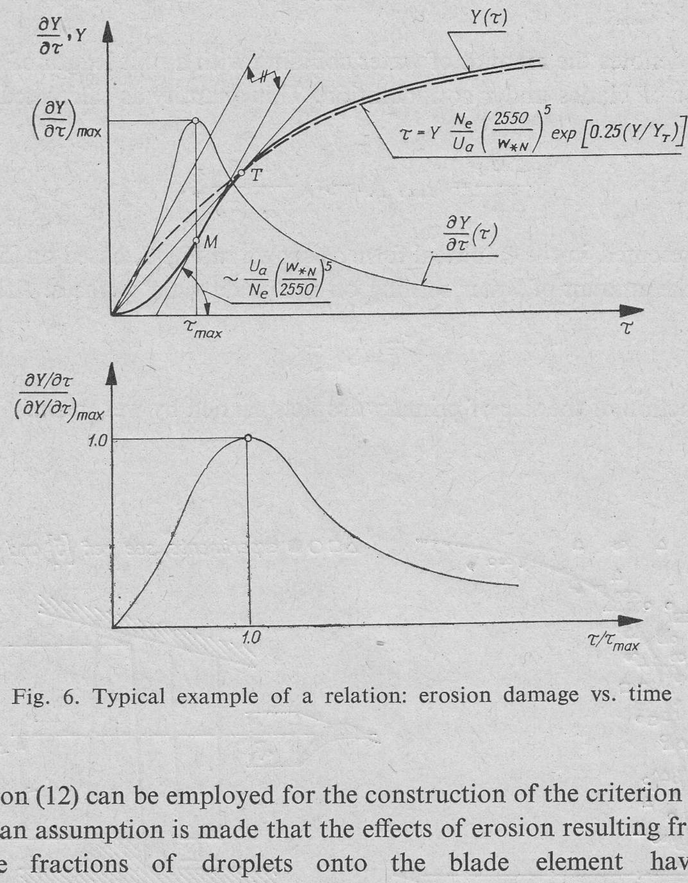

Fig. 6. Typical example of a relation: erosion damage vs. time

The relation (12) can be employed for the construction of the criterion of erosion threat of blading if an assumption is made that the effects of erosion resulting from impingement of respective fractions of droplets onto the blade element having dimensions $d\eta/(\sin\beta_{bl}(\eta))\cdot\Delta R_1$ are subject to superposition. Indeed, a blade surface element of such dimensions undergoes collisions with fractions of droplets having radii $r_{*\min}\leqslant r_*\leqslant r_*(\eta)$. Each fraction has a different angle of incidence and different velocity w_{*N}. This implies superposition consisting in seeking a sum of expressions:

$$\sin\beta_{bl}(\eta)\,\frac{\delta M_*(r_*,\eta)}{\rho_*\,d\eta\,\Delta R_1}\left(\frac{w_{*N}(r_*,\eta)}{2550}\right)^5 \tag{13}$$

over the interval of droplet radii $r_{*\min}\leqslant r_*\leqslant r_*(\eta)$. Such a sum was calculated in [8] and [9], the results having been similar to (10) and (11):

$$U_{eM}(\eta)=\sum_{r_{*\min}}^{r_*(\eta)}\sin\beta_{bl}(\eta)\,\frac{\delta M_*(r_*,\eta)}{N_e\rho_*\,d\eta\,\Delta R_1}\left(\frac{w_{*N}(r_*,\eta)}{2550}\right)^5=$$

$$=\frac{1}{N_e\rho_*}\frac{\Delta M_*}{\Delta R_1}\frac{1}{t_w}\frac{1}{\int\limits_0^{r_{\max}} w_{*ax}(r_*,\eta=0)\,r_*^3 f_n(r_*)\,dr_*}\times$$

$$\times\int\limits_{r_{*\min}}^{r_*(\eta)} w_{*N}(r_*,\eta)\,r_*^3 f_n(r_*)\left(\frac{w_{*N}(r_*,\eta)}{2550}\right)^5 dr_* = \frac{1}{N_e\rho_*}\frac{\Delta M_*}{\Delta R_1}\,UEM(\eta). \tag{14}$$

Here $\Delta M_*/\Delta R_1$ denotes the amount of water colliding with a unit length of a single rotor blade of the row of blades under consideration. This quantity as calculated in [8] and [9] equals to:

$$\frac{\Delta M_*}{\Delta R_1}=c_{1ax}\,\rho_1(1-x)\frac{y(l)}{y_{sr}}\frac{z_k}{z_w}\,\bar{\xi}, \tag{15}$$

$y(l)/y_{sr}$ can be presented in the empirical form as shown in Fig. 7, based on [5], $\bar{\xi}$ represents the measure of the amount of water settling on the guide vane surfaces. After [25] it was expressed as:

$$\bar{\xi}=S_{1k}\,\bar{g}_k, \tag{16}$$

where $\bar{g}_k$ is a function of the size of primary droplets carried by wet steam.

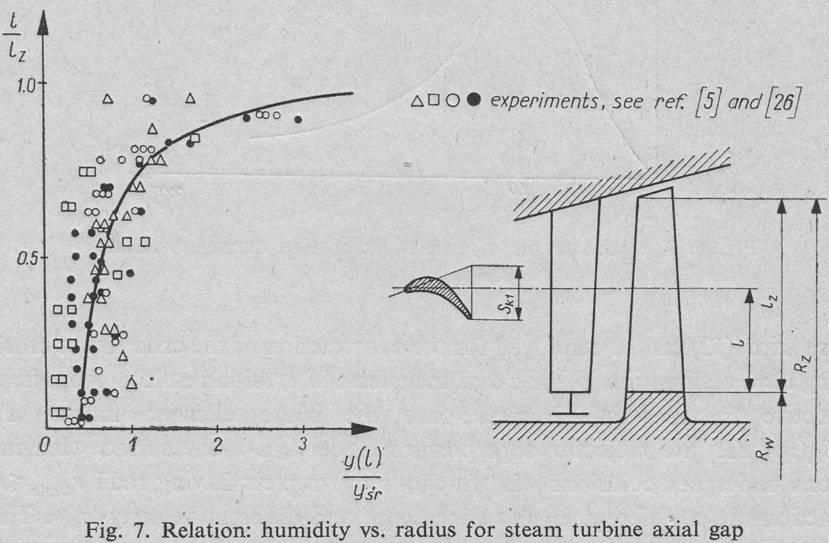

Fig. 7. Relation: humidity vs. radius for steam turbine axial gap

Hence, after substituting (14), (15) and (16) into (12) one obtains finally:

$$\tau=Y\frac{N_e\exp[0.25(Y/Y_T)]}{\frac{1}{\rho_*}c_{1ax}\,\rho_1(1-x)\frac{y(l)}{y_{sr}}\frac{z_k}{z_w}S_{1k}\bar{g}_{1k}\,UEM(\eta)} \tag{17}$$

or

$$\tau F'\equiv\tau S_{1k}\,c_{1ax}\,\rho_1(1-x)\frac{y(l)}{y_{sr}}\frac{z_k}{z_w}=Y\frac{N_e\rho_*\exp[0.25(Y/Y_T)]}{\bar{g}_k UEM(\eta)}. \tag{18}$$

This relation can be used to formulate a new criterion of erosion threat. It is similar in form to the previous proposal of the authors [1, 5]. The term $UEM(\eta)$ is the new element. Apart from being a function of η this term allows also taking into account the structure of the primary droplet stream. In Section 2 of this paper a way of linking this structure with the conditions of steam expansion in the turbine was presented.

The relation (18) can be used for construction of a criterion of erosion threat through an appropriate use of the results of inspection of erosion effects on blades of various modern turbines of great output. For selected blade profiles the value of $\tau \cdot F'$ can be calculated; also selected points of the profile can be assigned a certain erosion state, according to the scale determined, and also the value of $UEM(\eta)$. These data permit making a diagram of $\tau F' = f[UEM(\eta)$ and erosion state]. Points denoting particular erosion state of the blade sections examined will be concentrated in this diagram in the areas corresponding to a certain state of erosion threat. The areas can be separated by the lines $Y=\text{const}$, after an adequate selection of the value of the $Ne\rho_*/\bar{g}_k$ complex. As to this complex an assumption can be made that its value is constant for modern steam turbines.

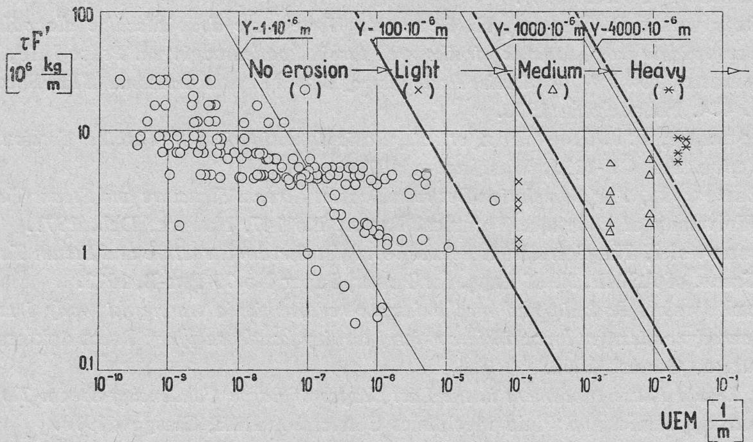

Fig. 8. Criterion of erosion threat

The procedure outlined in this paper was applied to the results of inspection of a group of 200 megawatt turbines as presented in [1]. The diagram $\tau F = f[UEM(\eta)$, erosion state] was constructed basing on characteristic points of eroded areas of the examined profiles. The points of maximum $UEM(\eta)$ values and the points located at η_B were chosen, the co-ordinate η_B defining the margin of the eroded area on a chosen profile. The results are shown in Fig. 8.

5. Concluding remarks

The relation shown in Fig. 8 represents the new form of the criterion of erosion threat of the modern steam turbine blading. This criterion defines the co-ordinates of the areas of no erosion and of weak, moderate or heavy erosion. The scale designed to classify these states of erosion was presented in [1]. In Fig. 8 also a curve of constant erosion depth is shown. The new form of the criterion of erosion threat makes it possible to examine the influence on erosion of such essential parameters of a turbine like the degree of machine load, enthalpy drop across a stage, pressure in the axial gap, dimension of the axial gap, the manner of blade twisting, selection of rotor blade profiles etc. Results of such investigations will be reported separately.

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Poprzez strukturę strumienia kropel ku kryterium zagrożenia erozją łopatek turbin parowych

Streszczenie

W ostatnim czasie pojawiło się wiele prac eksperymentalnych, określających warunki generacji i ruchu kropel w śladzie aerodynamicznym. Szczególnie interesujące z punktu widzenia erozji układu łopatkowego turbin parowych są informacje dotyczące struktury strumienia kropel w śladzie. Jak bowiem pokazano poprzednio [8, 9], struktura kropel, zdefiniowana funkcją rozkładu wielkości kropel, istotnie wpływa na szereg parametrów kolizji strumienia kropel z łopatką. W pracy zaproponowano opisanie rozkładu masowego kropel w strumieniu za pomocą tzw. funkcji $\beta(r_*)$. Przytoczono też wyniki eksperymentalne definiujące krytyczną wartość liczby Webera We_{kr} (rys. 1). Te dwie informacje pozwalają opisać funkcje rozkładu ilościowego (3) i objętościowego (4) dla strumienia kropel w szerokim zakresie liczb Macha. Na tej podstawie i opierając się na [8, 9], można obliczyć szereg istotnych parametrów kolizji, m. in. (10), (11), (14). To pozwoliło z kolei sformułować nową postać półempirycznego kryterium zagrożenia erozją łopatek turbin pracujących w parze mokrej (18) (rys. 8). Wykorzystano w tym celu obszerne wyniki oględzin stanu erozji szeregu współczesnych turbin parowych.

От структуры капель до критерия эрозионной угрозы для турбинных лопаток

Резюме

За последнее время появился ряд экспериментальных работ, определяющих условия возникновения и движения капель в аэродинамическом следу. Особенно интересными, с точки зрения эрозии лопаточной системы паровых турбин, являются информации, касающиеся структуры потока капель в следу. Как показано раньше [8, 9], структура капель, описанная функцией распределения величин капель, существенно влияет на ряд параметров коллизии потока капель с лопаткой. В работе предлагается описание массового распределения капель в потоке при помощи т. наз. функции $\beta(r_*)$. Приведены также экспериментальные резултаты, определяющие критическое значение числа Вебера We_{kr} (рис. 1). Эти две информации позволяют описать функции количественного (3) и объёмного (4) распределения для потока капель в широком диапазоне чисел Маха. На этой основе и на основе [8, 9] можно вычислить ряд существенных параметров коллизии, м. пр. (10), (11), (14). Это в свою очередь позволило сформулировать новую форму полуэмпирического критерия эрозионной угрозы для турбинных лопаток, работающих во влажном паре (18) (рис. 8). С этой целью использованы богатые результаты осмотров состояний эрозии ряда современных паровых турбин.