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Industrial Compressor Impeller Strength Evaluation

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Abstract: Impellers are for our company subject of experimental stress analysis, because are the most important parts of the compressors. All information about impellers are key to the development of our company, therefore is testing of impellers our integral part.

Keywords: Impeller; Over-Spin Test; Non Destructive Testing.

1 Introduction

An impeller is a key structural part of an industrial turbo-compressor. The machine parameters are given namely by a rotor speed. For the high-sophisticated product, an effort to speed increase up to material limit is emphasized. Impeller behavior is studied from the mechanical point of view and appropriate analysis methods and evaluation criteria are submitted.

2 Standards

2.1 Product

Impeller design, manufacture and quality assurance are described in product standards. API 617 or ISO 10439-1 are the best known specifications. The over-spin test of each specimen is often demanded. This "virgin" load exceeds the operation one by 15 to 21 %. Except traditional demonstration of object integrity, over-load causes plastic deformations in the critical areas.

2.2 Material

Impellers are made from steel or titanium alloy. Other materials, such as aluminium, may be used in specific applications. Material limits are listed in relevant standard. A minimal strength is referred to chosen heat treatment. It is practical to use international standards for communication between designer and supplier, e.g. EN 10250-4 for steel forgings.

2.3 Low-Speed Balancing

For better properties of impellers and balanced rotation of train, the impellers are balanced. The impellers are usually balanced by taking away some material from the impellers. For this process of determination the best properties of impellers, a balancing machine is used, Fig. 1.

3 Theory

3.1 Stress Distribution

An impeller load comes from mainly centrifugal movement. Rotating disc may burst. However blading causes stress concentration in the blade to shroud or blade to hub joins. Because of mechanical design is driven by flow channel optimized for aerodynamics, there are several isolated critical areas.

Fig. 1: Low-speed balancing machine.

3.2 Plastic Deformation

A plastic part of stress-strain curve is exploited in the course of initial over-spin test. Cyclic deformation should be considered.

Example of test report balancing, overspeed testing and dimensional check of impellers is shows in attachment.

4 Methods

4.1 Stress Analysis

Impeller geometry is analyzed via finite element method. High level stress areas are optimized and maximum rotor speed is estimated.

4.2 Plastic Deformation

At the first step which is “over-spin” (once in a lifetime), the material may be partially plastic deformed (maximum half of a cross-section). The next steps plastic deformation has to remain the same (linear).

4.3 Over-Spin Test

Each manufactured specimen is tested in laboratory. A non-destructive testing is performed consequently. Sustaining of the over-spin gives potential to be operated without failure.

Example you can see in attachment.

5 Best Practice

5.1 Design Criterion

In the course of impeller design, the geometry is optimized from the thermodynamic as well as mechanical point of view. Stress analysis during design session has 2 purposes:

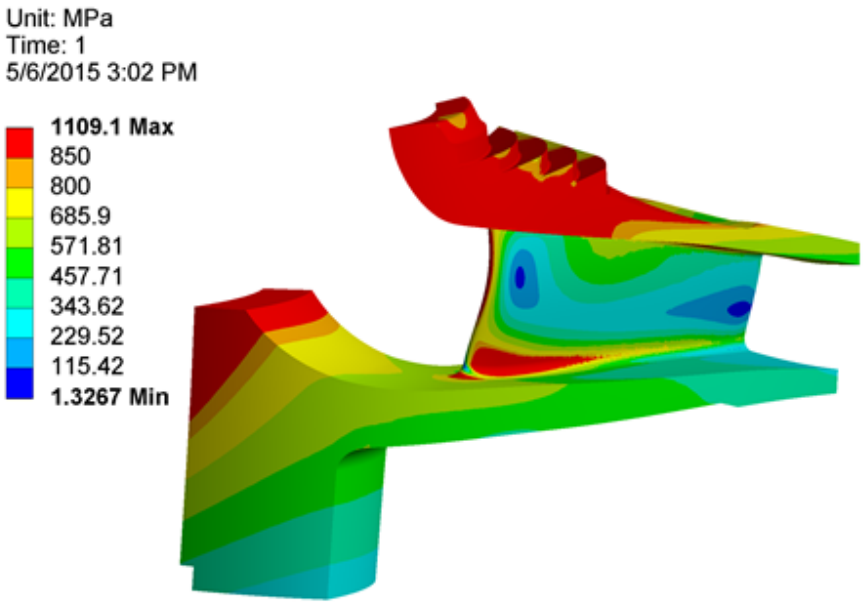


Fig. 2: Final element analysis stress von-Mises.

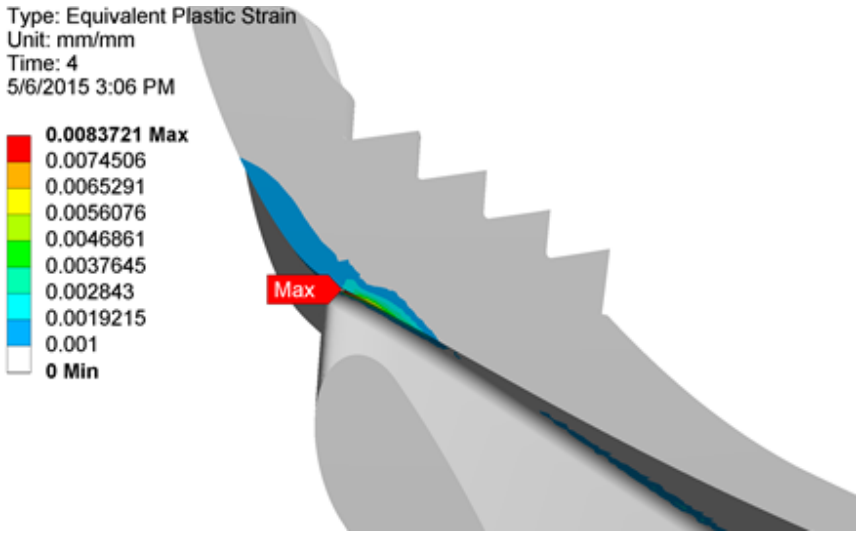


Fig. 3: Final element analysis equivalent plastic strain deformation (cross-section).

- critical areas identification and geometry optimization,
- impeller strength limit estimation.

Sufficient strength of the given specimen shall be experimentally verified prior machine operation because of safety as well as economic reasons. An appropriate criterion should be developed. It is proposed to evaluate

- maximal plasticity of material in critical area,
- plastic zone dimension related to full cross-section (max. half of the cross-section).

5.2 Experiment Evaluation

In the course of experimental session, the object carries an overload. The experiment evaluation provides us with 2 important QA items:

- maximal plasticity of material in critical area,
- plastic zone dimension related to full cross-section (max. half of the cross-section).

The first item is evaluated by the non-destructive testing. Traditional methods, e.g. liquid penetrants or magnetic particle, are used to be applied. For the second one, an appropriate criterion should be developed. Object strength evaluation is based on stress analysis. A plastic deformation after repeated application of the spin load is evaluated.

Fig. 4: Over-spin testing.

6 Conclusion

An industrial compressor impeller is subject of experimental stress analysis. Even a local material static strength exceeding is indicated via NDT or via loss of object integrity. Plastic deformation is evaluated via outside measurable dimension. Cyclic deformation curve is used for operation safety guarantee confirming numerical simulation results.

7 Attachment

PROTOKOL O VYVÁŽENÍ, ODSTŘEDĚNÍ A ROZMĚROVÉ KONTROLE OBĚŽNÉHO KOLA Č. 1
TEST REPORT BALANCING, OVERSPEED TESTING AND DIMENSIONAL CHECK OF IMPELLER No. 1

Howden

ISO 9001

VÝCHOZÍ ROVINA – ZAČÁTEK ČÍSLA VÝKOVKU NA NOSNÉM KOTOUČI
REFERENCE PLANE – BEGINNING OF THE FORGING NUMBER ON THE HUB DISK

A

B

1 2 3 4 5

Ø D_2

Číslo výkresu kola Impeller draw. No.	DC-11826-P-00717		Hmotnost kola Impeller mass	25,4 kg
Číslo výkovku nosného kotouče Hub disk forging No.	-		Číslo výkovku krycího kotouče Shroud disk forging No.	-

VYVÁŽENÍ KOLA / IMPELLER BALANCING — Maintenance Partners – 101J-HD STAGE 1 IMPELLER

Typ vyvažovacího stroje Balancing machine type	SCHENCK H30		Výr. č. vyvažovacího stroje Balanc. machine manufac. No.	AHE 1195
Přípustná nevyváženost dle ISO 1940 G 2,5 e=1,98 Permissible unbalance	50,2	gmm	Vyvažovací otáčky Balancing speed	1 340 1/min
Počáteční nevyváženost R=210mm Initial unbalance	1575	gmm	Provedl Performed	Petr Holý
Zbytková nevyváženost Residual unbalance	14,7	gmm	Datum Date	22.4.2015 Podpis / Signature

ROZMĚROVÁ KONTROLA OBĚŽNÉHO KOLA / DIMENSIONAL CHECK OF THE IMPELLER — Maintenance Partners – 101J-HD STAGE 1 IMPELLER

Měřené místo / Measurement point		1	2	3	4	5
Přípustné trvalé deformace Permissible pernament deformation			0,000 09. D2 min. 0,03 mm		0,000 11. D2 min. 0,04 mm	
Průměry před odstředěním Diameters before overspeed test	A	305,030	153,500	152,310	454,070	454,030
Průměry před odstředěním Diameters before overspeed test	B	305,050	153,500	152,310	454,090	454,050
Průměry po odstředění Diameters after overspeed test	A	305,050	153,500	152,310	454,080	454,050
Průměry po odstředění Diameters after overspeed test	B	305,050	153,500	152,310	454,110	454,070

Teplota měřeného kola před odstředěním Temperature of measured impeller before overspeed test	°C	Provedl: Performed:	
Teplota měřeného kola po odstředění Temperature of measured impeller after overspeed test	°C	Datum: Date:	23.4.2015 Podpis, razítko / Signature, stamp

ODSTŘEDĚNÍ KOLA / OVERSPEED TEST OF THE IMPELLER — Maintenance Partners – 101J-HD STAGE 1 IMPELLER

Typ odtřeďovacího stroje Overspeed machine type	B4 P	Výr. č. odtřeďovacího stroje Overspeed machine manuf. No.	ABF 0009
Odstřeďovací otáčky Overspeed	13 869 1/min	Provedl Performed	Petr Holý
Doba Duration	1 min	Datum Date	22.4.2015 Podpis / Signature

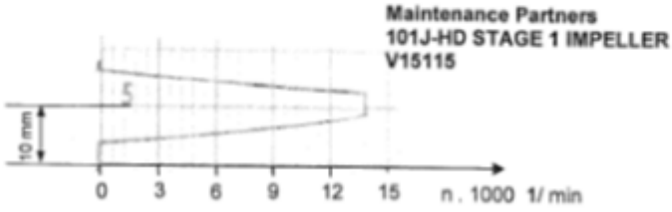
Heslo Code	Maintenance Partners	Zakázkové číslo Order No.	V15115 POČ OrderConf. No. -
Příloha – průběh odstřeďování kola Appendix – course of overspeed			Typ Type -
Schválil : Approved : Datum : Date :	Výsledek měření / Result of measurement: [X] vyhovuje / acceptable [ ] nevyhovuje / non-acceptable Podpis, razítko / Signature, stamp		Číslo: Number: MP-PZZ-001A

Fig. 5: Test report balancing, overspeed testing and dimensional check of impeller 1/2.

Howden | ISO 9001 LLC (Certification) | **PROTOKOL O ODSTŘEDĚNÍ** / **TEST REPORT – OVERSPEED** | Číslo / Number: **MP-PZZ-002A**

Zákazník / Customer	**Maintenance Partners**			
Název / Code	**101J-HD STAGE 1 IMPELLER**			
Konto ČKD Kompresory / Order No	**V15115**	Číslo výkresu / Drawing No.	-	
Typ odstředivacího stroje - Schenck / Overspeed machine type	**B4 P**	Výrobní číslo / Manufacturing No.	**ABF 0009**	
Odstředovací otáčky / Overspeed	[1/min] [rpm] **13 869**	Doba odstředění / Duration	**1**	**[min]**

Záznam o odstředění / Record of overspeed test :



Poznámka / Note : Shift of plotting paper 10 mm => 3 min

	Jméno / Name	Datum / Date			
Kontrola / Reviewed	**Petr Holý**	**22.4.2015**	Podpis / Signature		
Schválil : / Approved :		Výsledek měření / Result of measurement	[X] vyhovuje / acceptable	[ ] nevyhovuje / non-acceptable	
Datum : / Date :		Podpis, razítko / Signature, stamp			

Fig. 6: Test report balancing, overspeed testing and dimensional check of impeller 2/2.