Energy efficient material normalisation with vibratory stress relief

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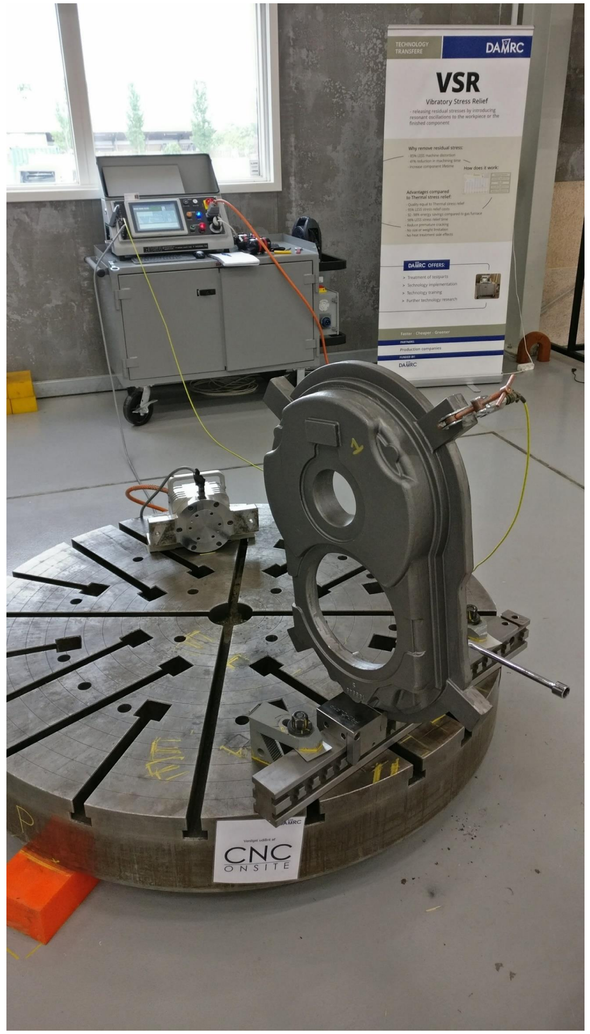
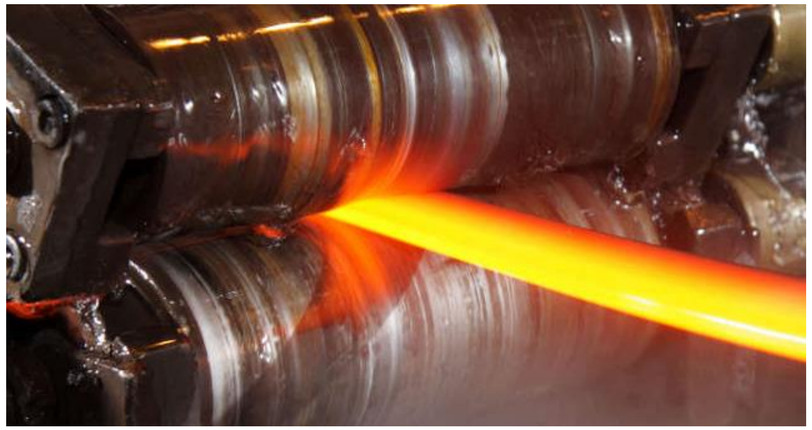
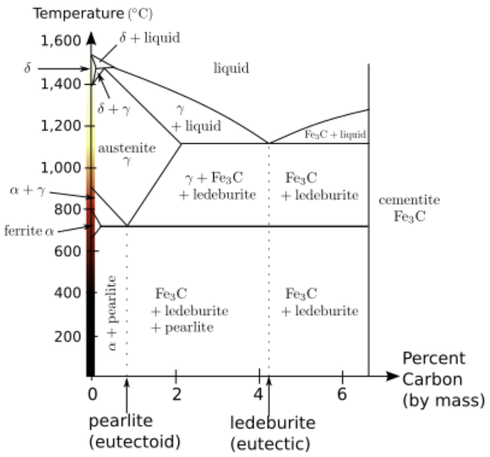
Agenda

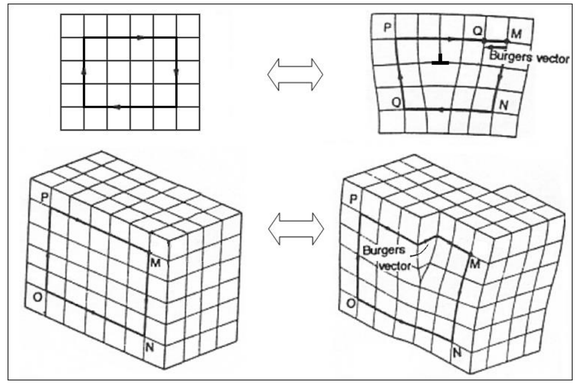
- Introduction to residual stress, and how to deal with it
- Vibratory Stress Relief (VSR)
- Energy consumption of stress release
- Review of performed VSR treatments
- Summery and conclusion

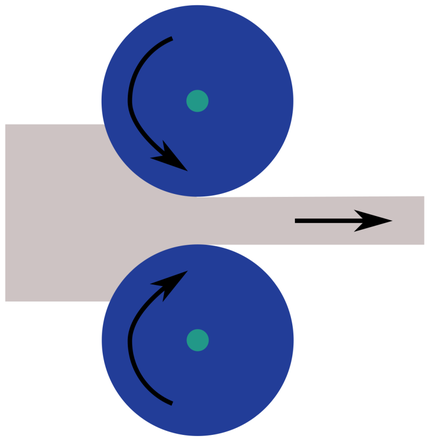


Residual stress – a result the fabrication processes



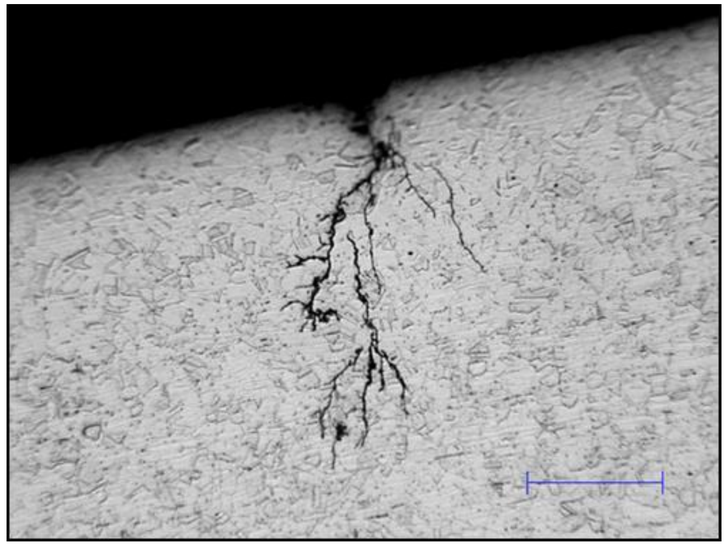






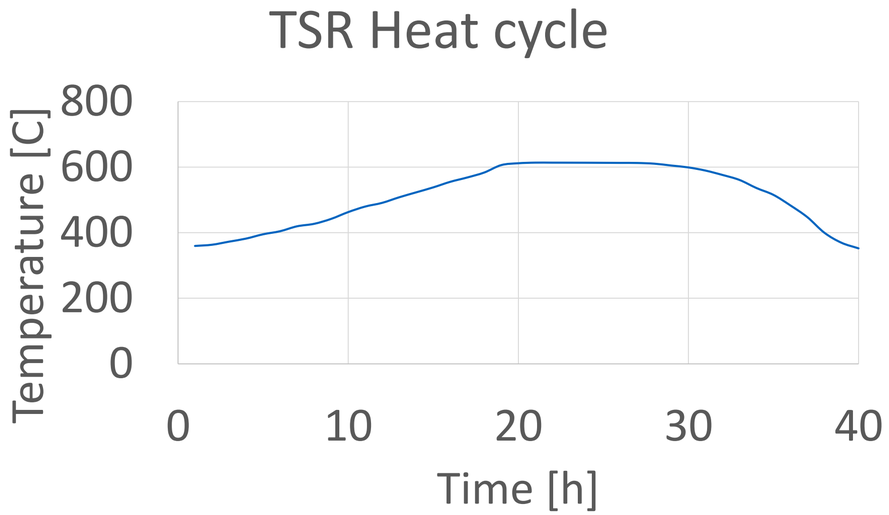
Is residual stress a bad thing?

- Deflection in parts during machining
- Lead to stress corrosion
- Compressive stress can increase fatigue life



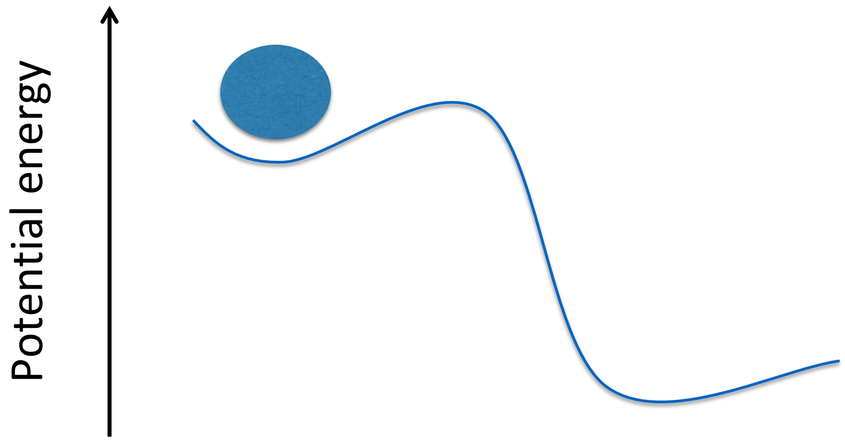
Thermal Stress Release (TSR)

- Well known technology
- Energy demanding
- Time consuming
- Limited use on
  - Austenitic stainless steel
  - Age hardened steel
  - Aluminium

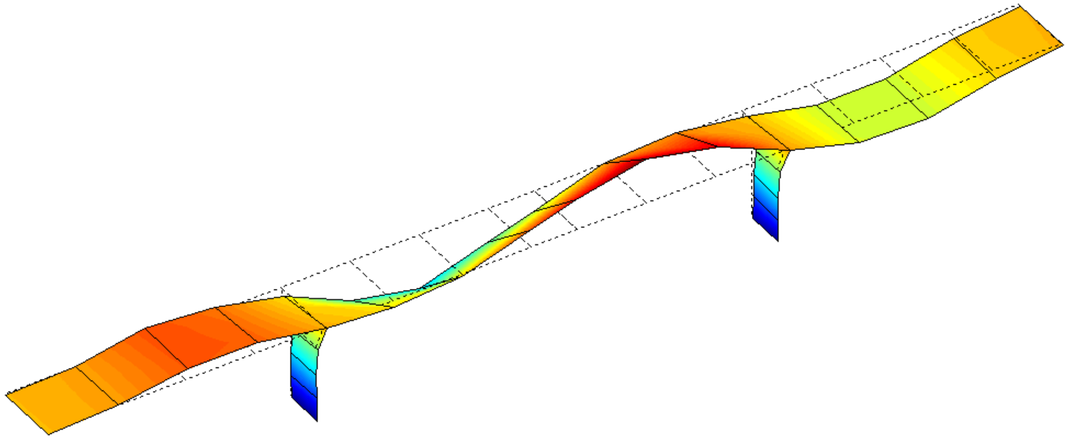


What is Vibratory Stress Relief (VSR)?

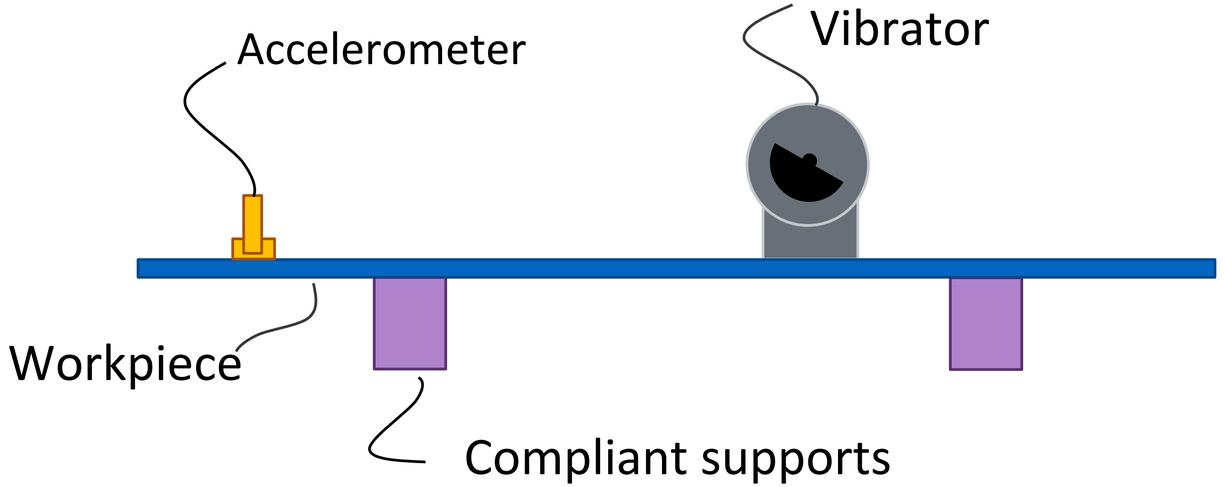
- Residual stress is stored elastic energy.
- Vibrations are used to release the stored energy.
- Microstructural processes are still a research field



Setting up a VSR treatment



Simulated modeshape



Plasticity model for the operation of VSR

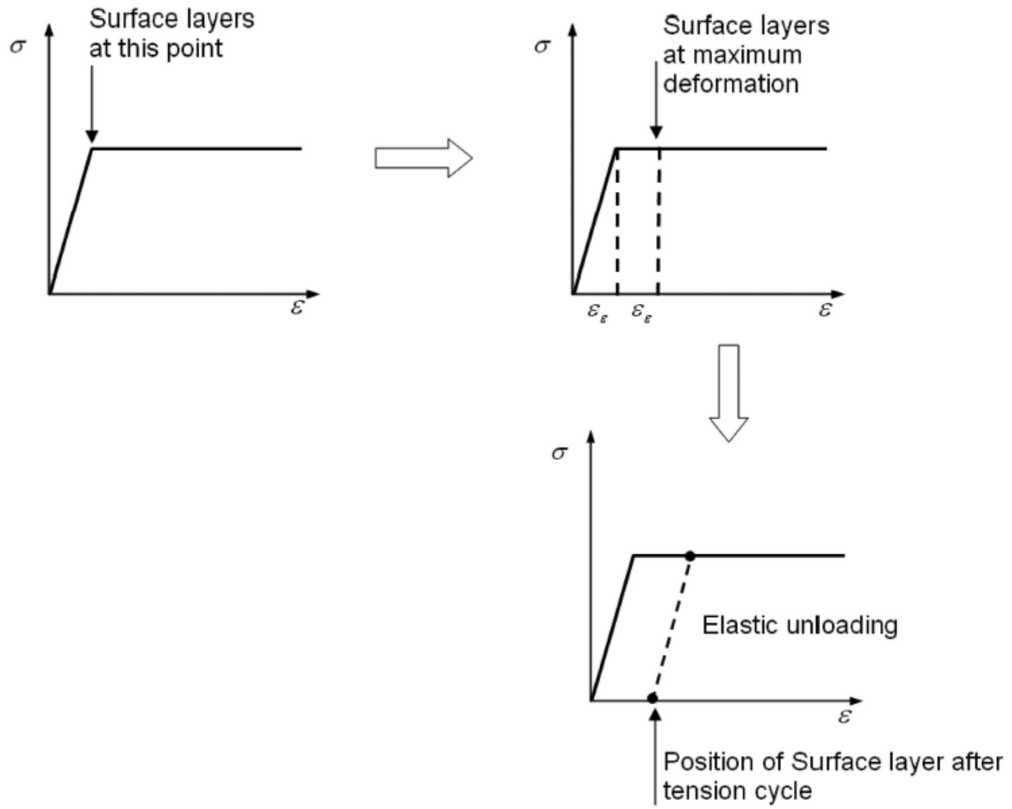


Fig. 1 Mechanism of stress relief in the plasticity model of VSR

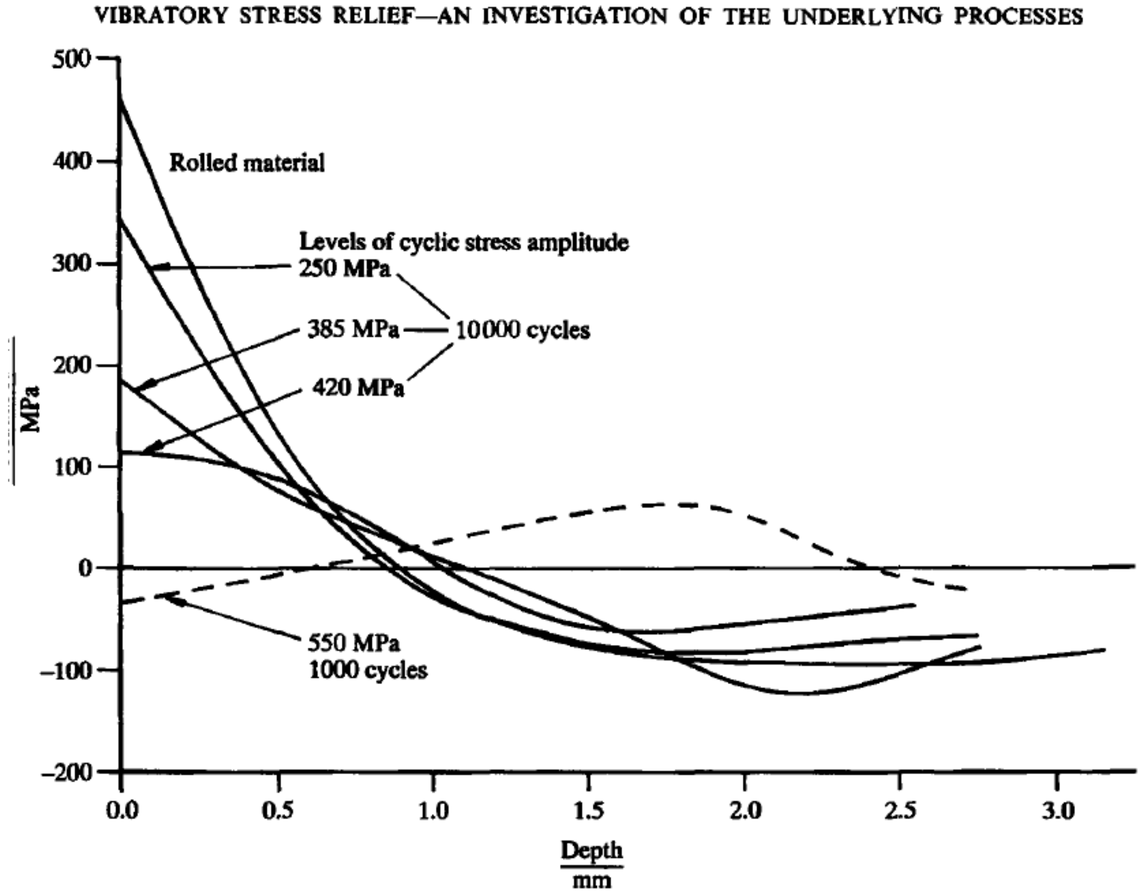
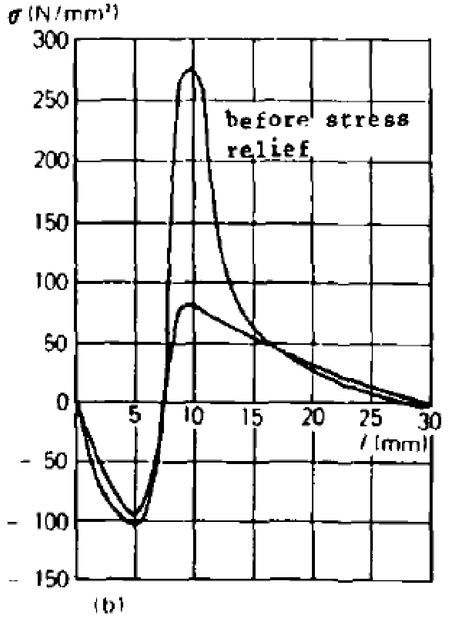


Fig. 3 Effect of cyclic loading upon surface residual stress in mild steel EN3b

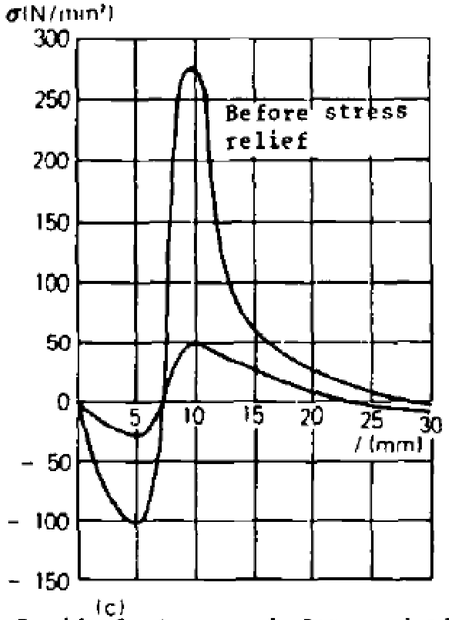
Walker, C. 2011

Vibratory stress release (VSR)

Unalloyed steel with residual stress in same order as yield limit, S235



Residual stresses before and after vibratory stress relief



Residual stresses before and after stress relief by heat treatment

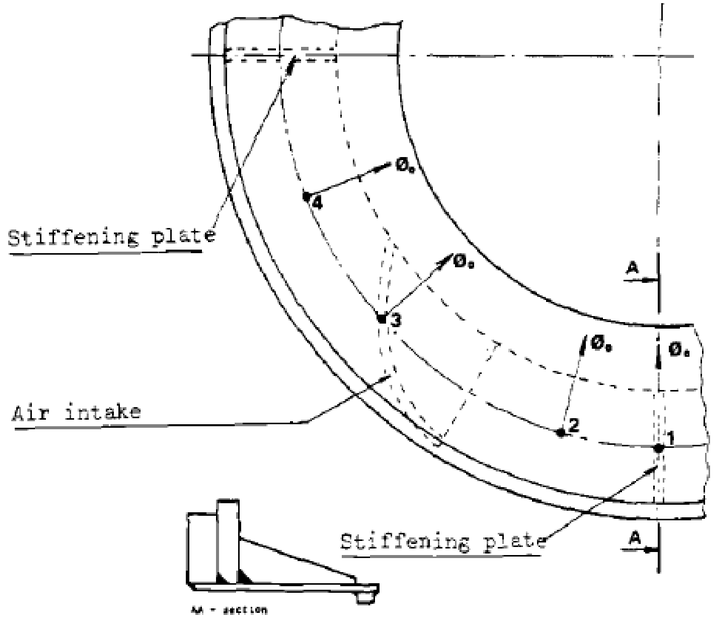
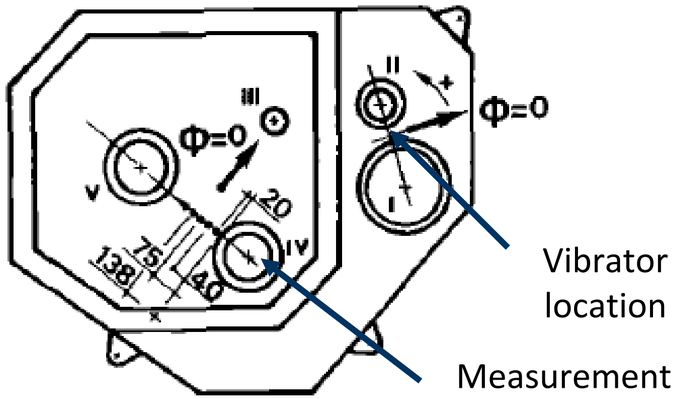


FIG. 15—*Pump unit component, locations of measurement points of residual stresses.*

Vibratory Stress Relief of Welded Parts—C. BOUHELIER et al.

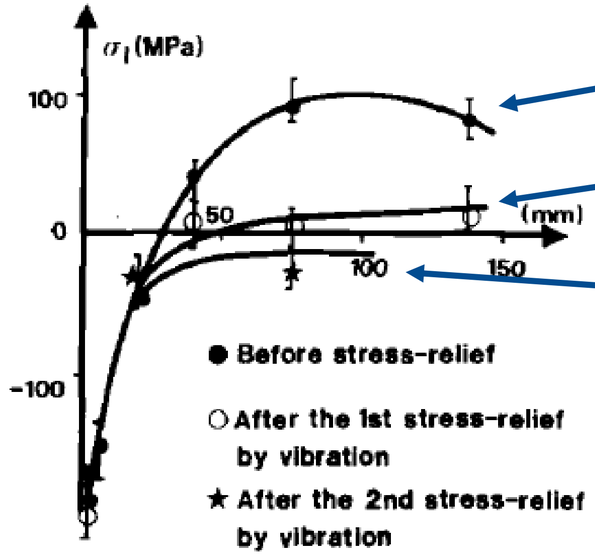
Double VSR treatment

- VSR 1, Sub-resonant 30 Hz Stress amplitude <2MPa
- VSR 2, Resonant at 44 Hz, Stress amplitude 150 – 300 MPa
- Significant stress reduction even at low strain level, best effect on tension



Vibrator location

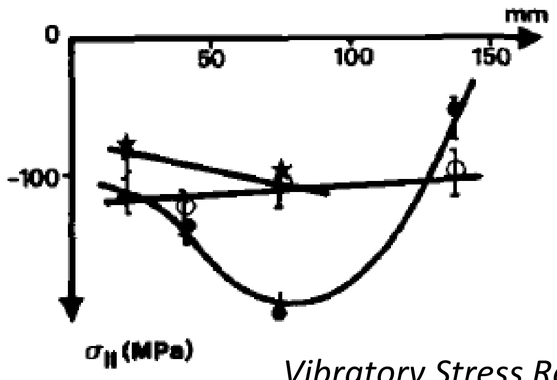
Measurement location

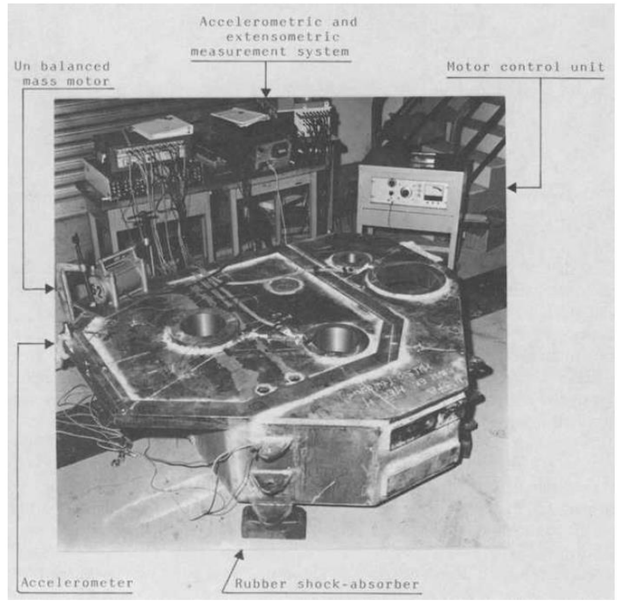


Initial stress level

VSR 1

VSR 2



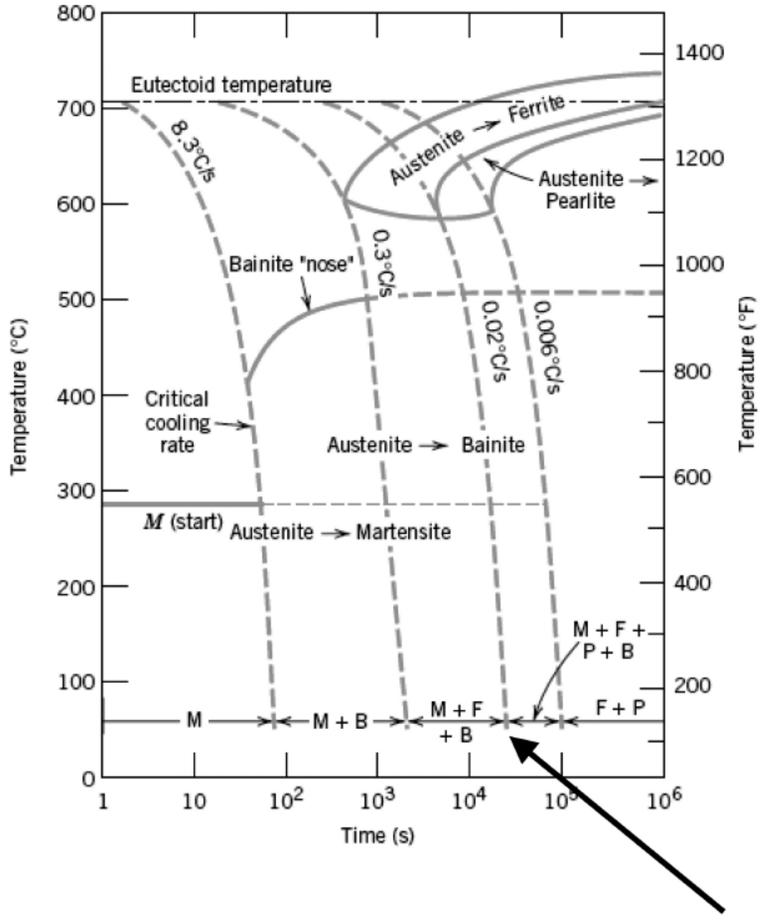


Vibratory Stress Relief of Welded Parts—C. BOUHELIER et al.

Residual stress reduction with 5 – 10 % of yield stress

One possible explanation:

- Large components cool slowly – allowing for austenite formation
- Transformation from Austenite to Martensite happens under large shear strain – This relieves residual stress
- Vibrations could start the transformation

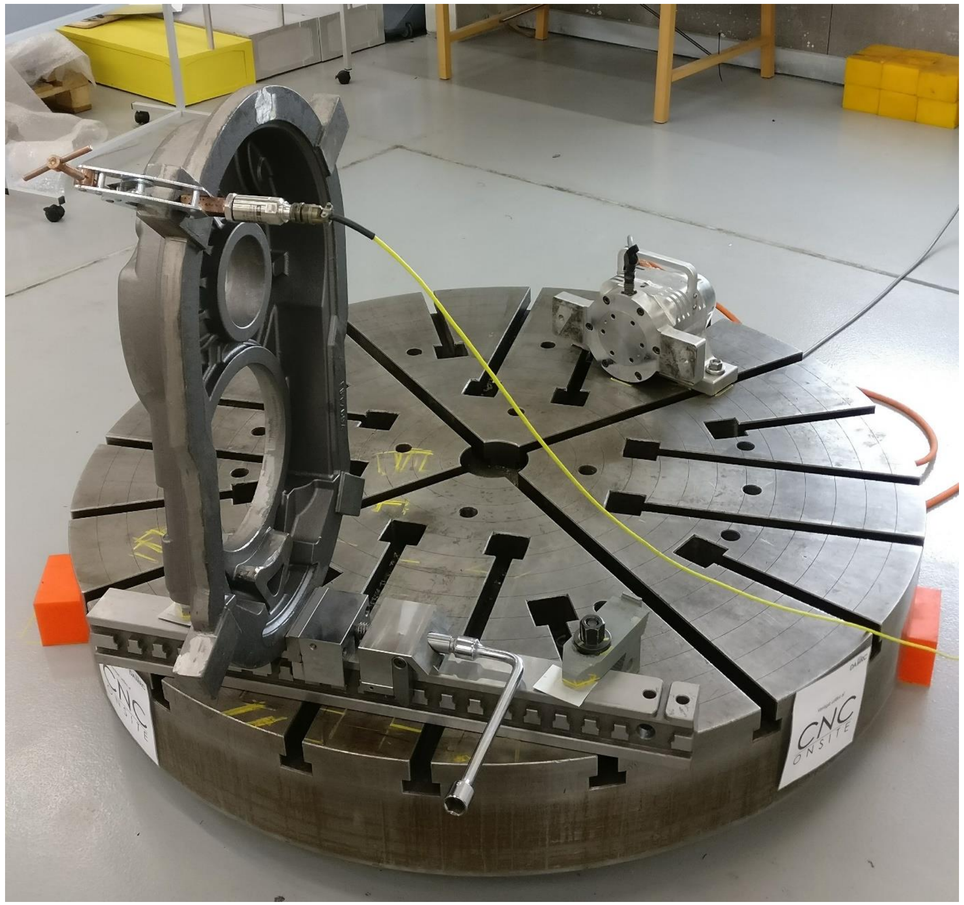


Approximate rate of cooling for a large casting (ref 11)

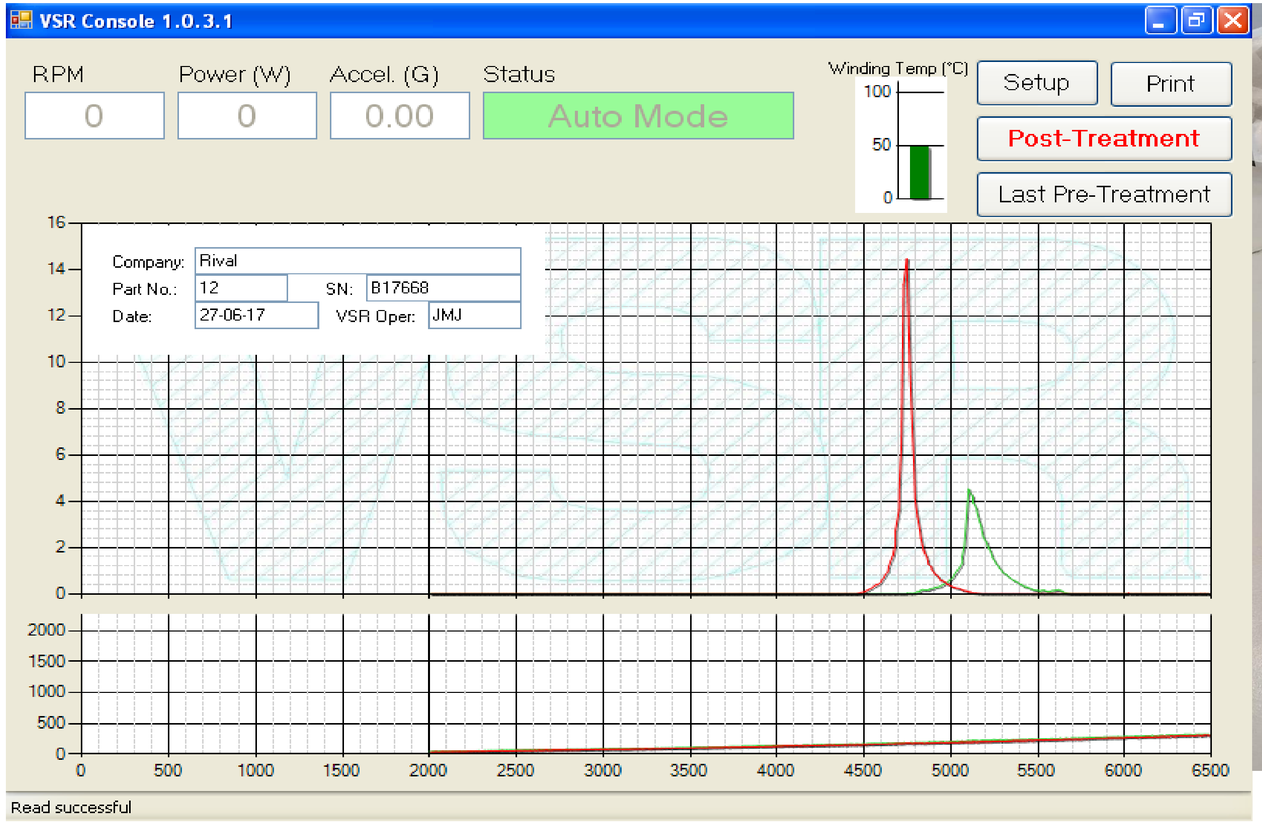
VSR on large parts

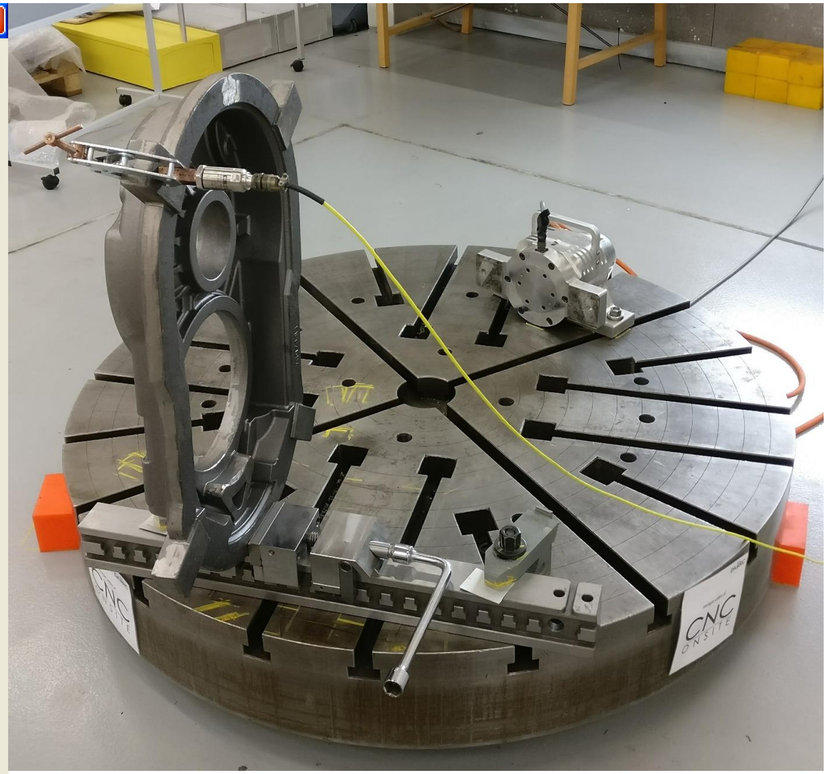
L1 Vestas V112 MK2 Hub

VSR on smaller parts

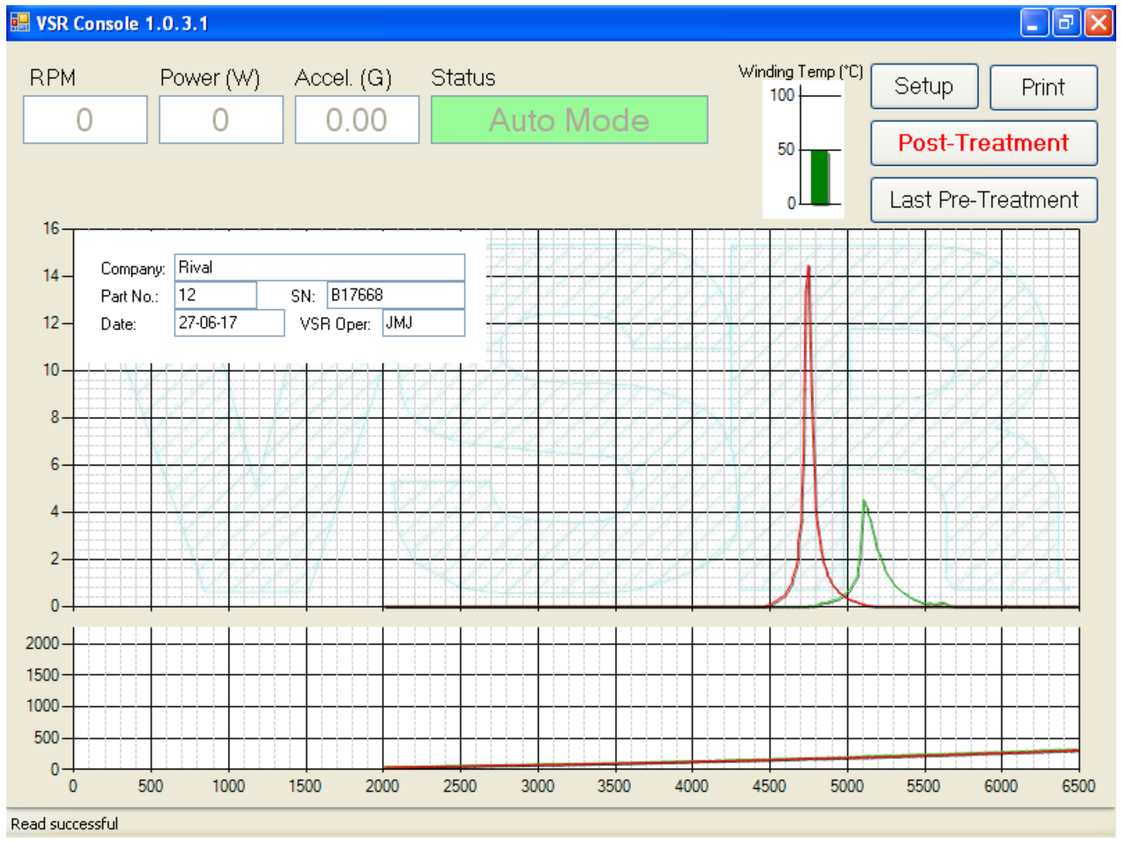


Frequency response before and after VSR

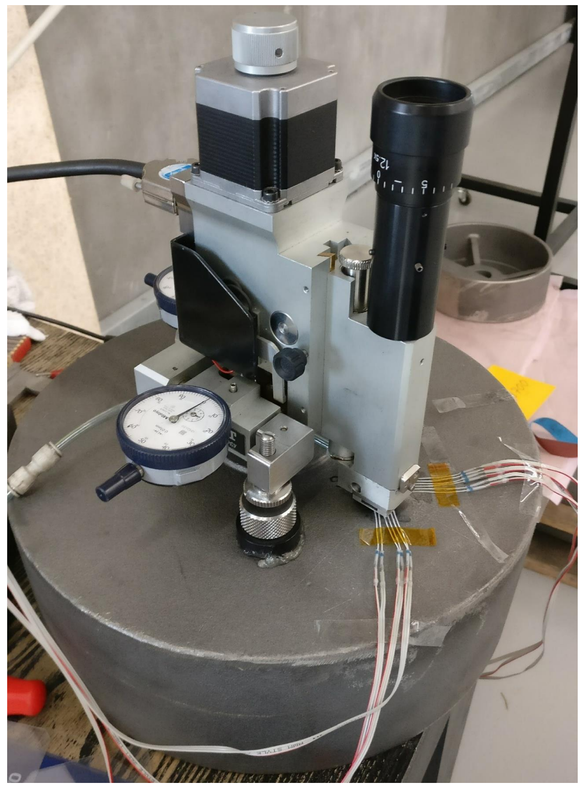


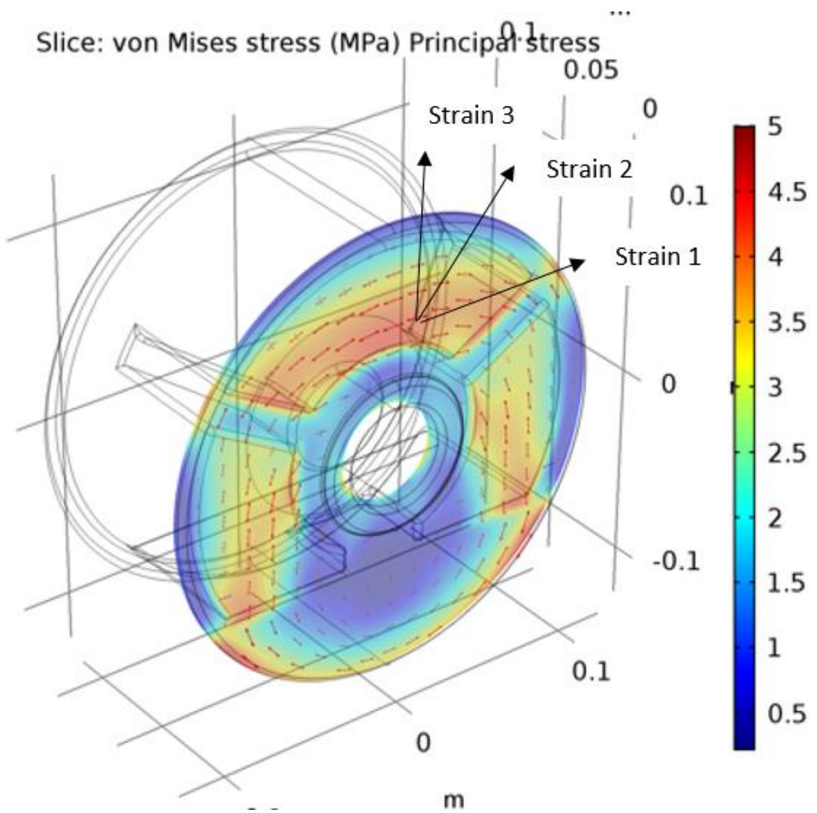


Improved repeatability – controlling boundary conditions

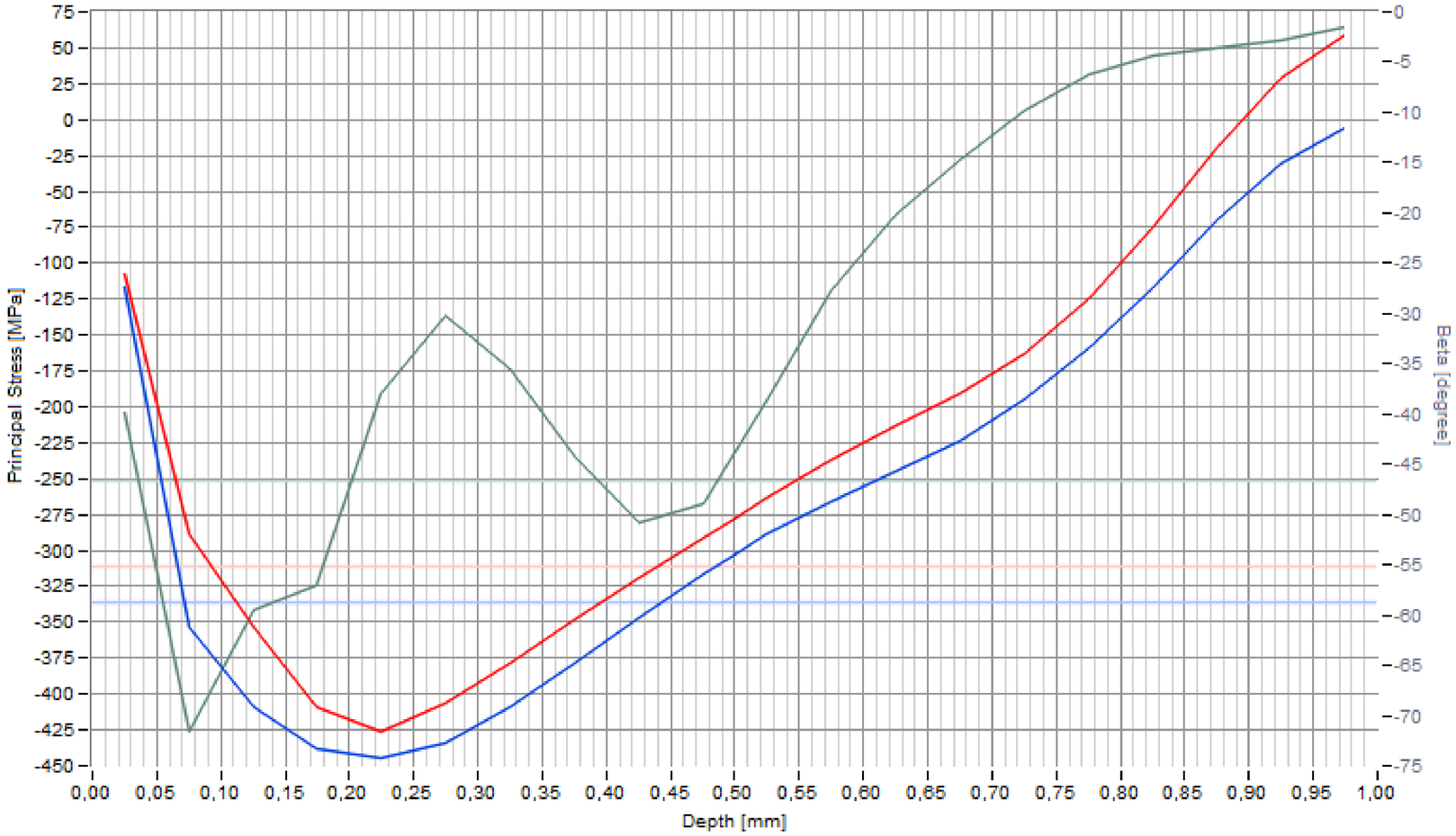


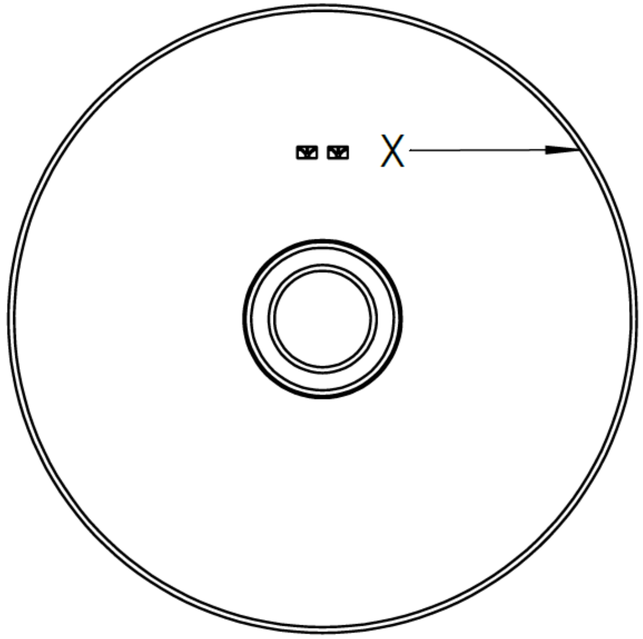
Evaluation of effectiveness





Residual stress in a cast iron component (S1)

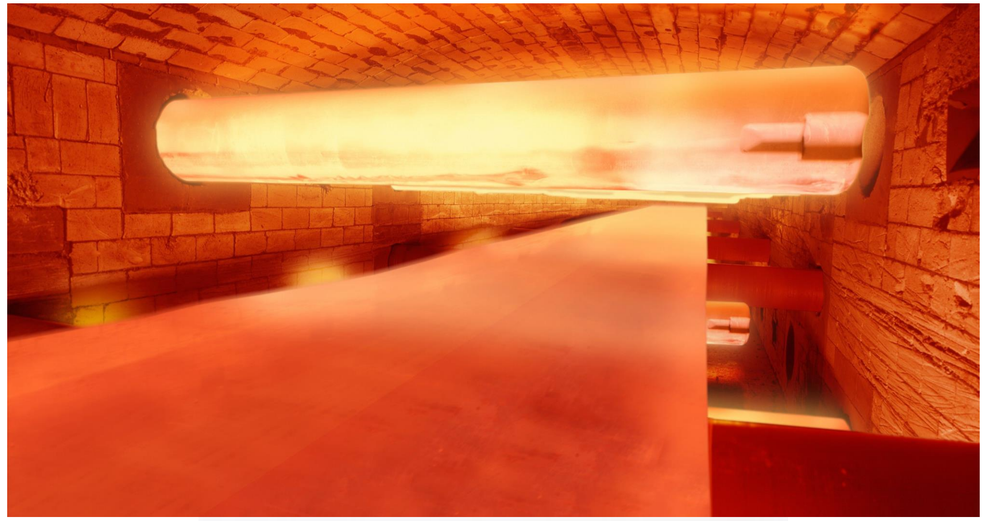




Energy consumption of stress release

- Heat treatment – Enthalpy required for reaching 600°C, assuming LPG powered furnaces with a thermal efficiency of 39 %.

$$Q_{TSR} = \frac{\Delta T\ m\ C}{\eta}$$



- VSR power – motor power over treatment time.

$$Q_{VSR} = t\ P_{vibrator}$$

VSR treatments in this project

13 different parts from various industries

- Size range
  - Large 0,5 to 126 ton
  - Medium 40 to 500 kg
  - Small less than 40 kg
- Materials
  - Structural steel, S235 and S355
  - Cast iron, GJL-200 and 250, GJS-400 and 500
  - Aluminium 7075 and EN AC 43000, F

Large parts

L1 Vestas V112 MK2 Hub

L2 Turbine tower section, 126 ton

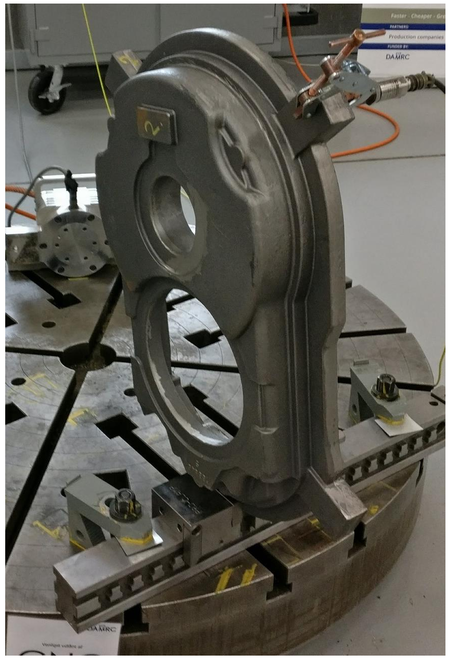
Large parts

Part ID	Number of parts	Part	VSR kWh/part	VSR time [min]	Weight [ton]	Material	Heat capacity [MJ]	TSR Consumption [MJ]	VSR [MJ]	Potential energy saving	Saved CO2 emission [ton]
L1	1	V112 MK2 hub	0.7	120	1.6	EN-GJS-400-18U-LT	12362	31698	2.4	**100%**	**1.8**
L2	1	Wind turbine tower section	0.7	120	126	S355	87321	223901	2.4	**100%**	**13**
L3	1	Generator platform	0.7	85	18	Structural steel	12474	31986	2.6	**99.992%**	**1.8**

Medium parts

M1

M3

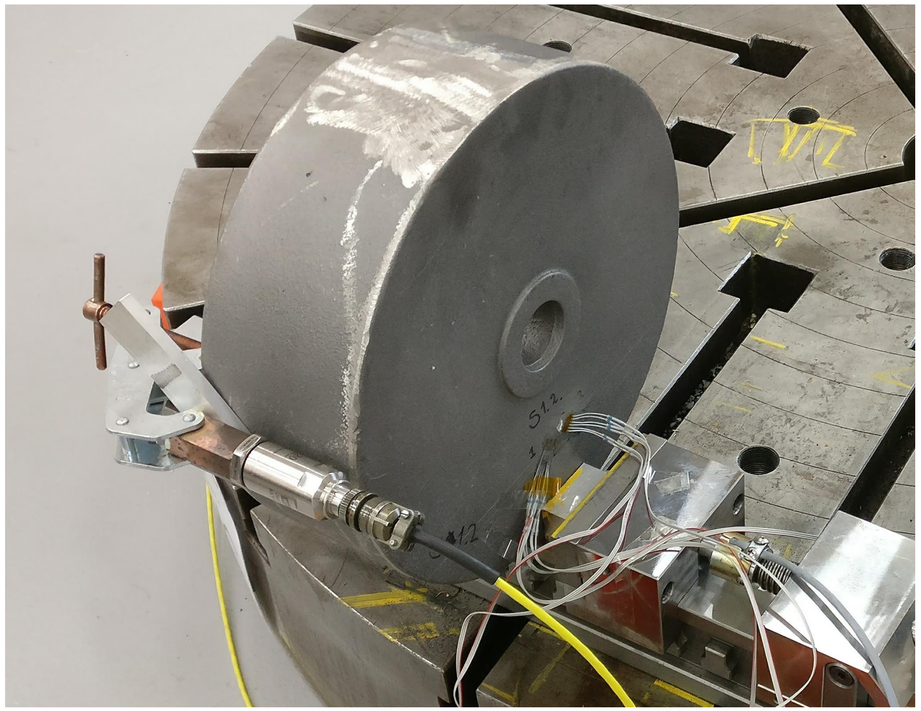


M5

Medium parts

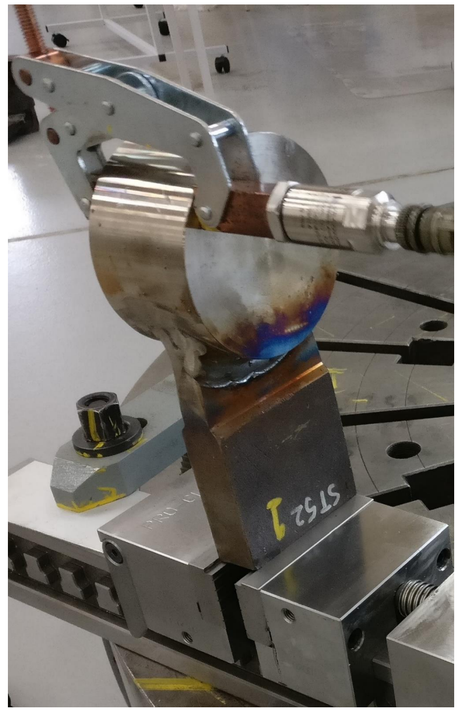
Part ID	Number of parts	Part	VSR kWh/part	VSR time [min]	Weight [kg]	Material	Heat capacity [MJ]	TSR Consumption [MJ]	VSR [MJ]	Potential energy saving	Saved CO2 emission [kg]
M1	6	Bearing house	0.4	40	126	S355	87	224		**100%**	**13**
M2	1	Screw conveyor	0.52	60	100	S355	69	178	1.9	**99%**	**10**
M3	2	Plane	0.35	20	84	GJL 250	67	171		**100%**	**10**
M5	47	Gearbox cover	0.39	30	45	GJS-600-3	36	92	1.4	**98%**	**5.1**

Small parts

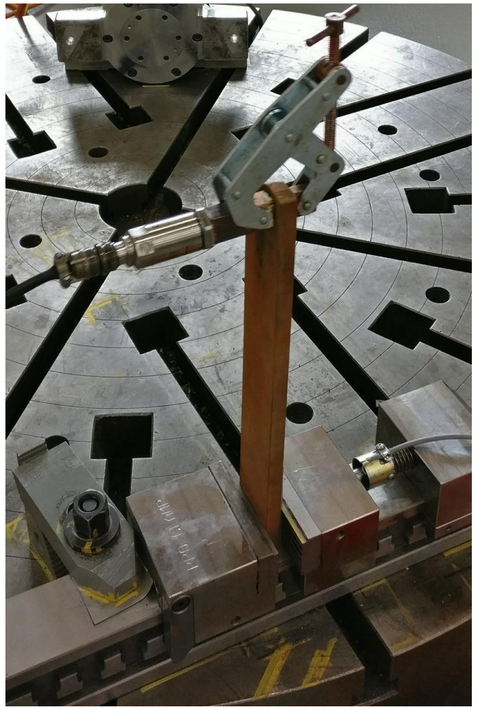


S1

S2



S3



S8

Small parts

Part ID	Number of parts	Part	VSR kWh/part	VSR time [min]	Weight [kg]	Materials	Heat capacity [MJ]	TSR Consumption [MJ]	VSR [MJ]	Potential energy saving	Saved CO2 emission [kg]
S1	2	Sheave	0.35	20	27	GJL 200	21	55		**100%**	**3**
S2	8	Alu plates	0.28	20	6.8	7075			1.0	-	
S3	3	Testpart steel 52	0.36	20	9	S355	6	16	1.3	**92%**	**1**
S4	3	Testpart hardox	0.36	20	9	Hardox			1.3	-	
S5	1	Thinwalled alu casting	0.25	40	4.4	EN AC 43000				-	
s8	2	flat cast bar	0.25	20	1.6	SG500	1	3	0.9	**72%**	**0.2**

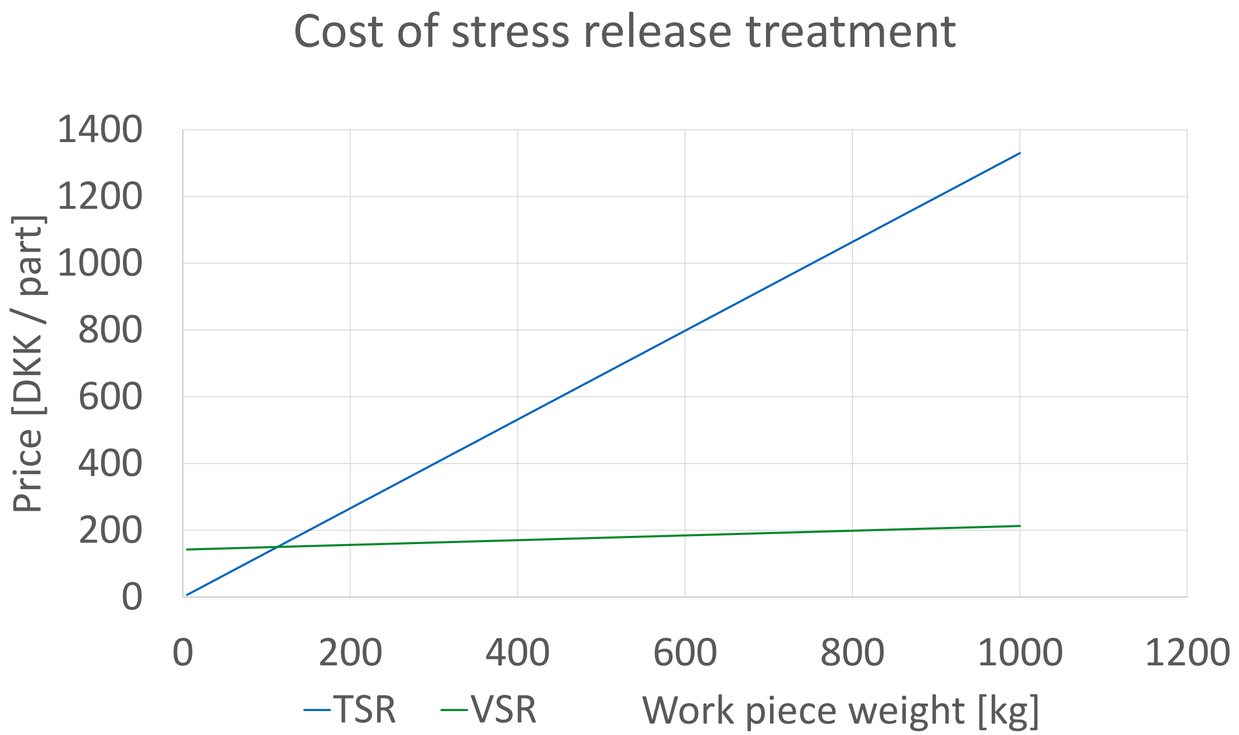
Cost comparison

TSR

- Transportation
- lead-time
- Equipment
- Energy

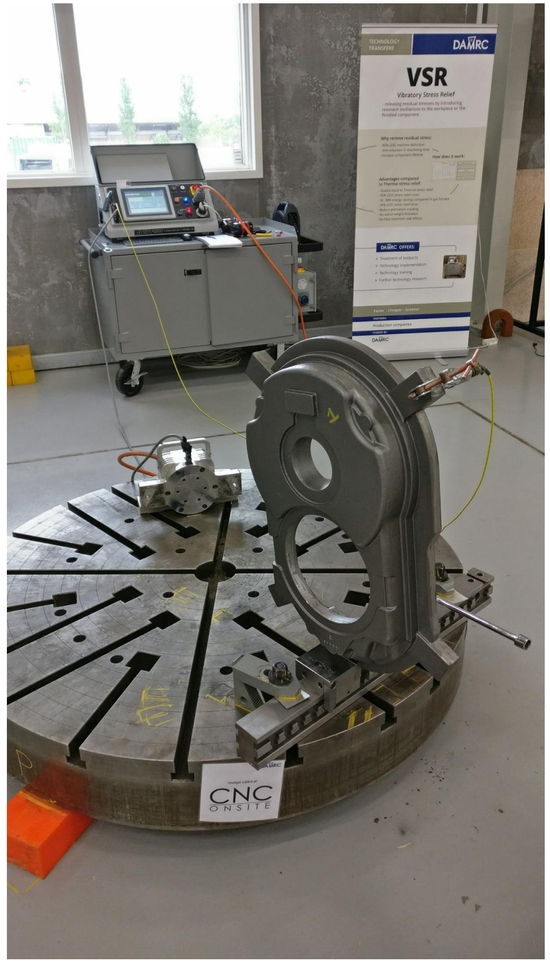
VSR

- Labour
- Equipment



Conclusion

- VSR treatments save 72 % to 100 % energy compared to TSR
- VSR can improve lead time
- Improved dimensional stability of part M5
- 1.8 ton of CO_2 emission avoided by treatment of part L3
- Successful implementation of VSR requires testing



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