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Extended Abstract

THERMAL BEHAVIOR AND COOLING CONDITIONS OF WET MULTI-PLATE CLUTCHES IN MODERN APPLICATIONS

TRACK OR CATEGORY
Tribotesting IV

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INTRODUCTION

Wet multi-plate clutches are important components in many driveline applications, e.g. power shift transmissions, and industrial use. Functional behavior and durability mainly depend on the thermal conditions of the clutch [1] [2]. Thermal behavior and especially cooling conditions of wet multi-plate clutches depend on many and often very complex influencing parameters. Design and lubrication as well as operating conditions and groove design with typical oil flow capacity and heat transfer show effects on the thermal conditions in the clutch [3] [4] [5]. In order to improve performance and efficiency, besides optimization of friction lining and lubricants, new groove arrangements and at the same time reduction of cooling oil volume flow are in focus of development.

Temperature measurements in clutches are feasible but challenging and time-consuming due to compact package and rotating parts. Moreover measurements only provide information on the local temperature curve at the measuring point – a complete temperature profile in the clutch can only be captured by thermal simulation. Besides high quality of modeling, reliable input data are required to display the thermal behavior and cooling conditions of wet multi-plate clutches [6] [7]. The calculation program KUPSIM [6] for thermal simulation of wet multi-plate clutches is introduced; a calculation example is shown to illustrate main program scopes.

THERMAL BEHAVIOR AND COOLING CONDITIONS

Factors that influence the thermal behavior of wet multi-plate clutches are highly diverse and complex. Mechanical load and therefore energy input in the friction contact determine peak temperatures. Heat dissipation and distribution depend on clutch design (size, number of friction plates, friction material, grooves, connecting components, etc.) and cooling oil flow conditions [3] [4] [5]. Moreover the shifting process (cycle time, cooling phases, load sequence, speed ration, etc.) has great influence on the thermal behavior of the clutch [4] [6]. Figure 1 shows a shifting cycle with

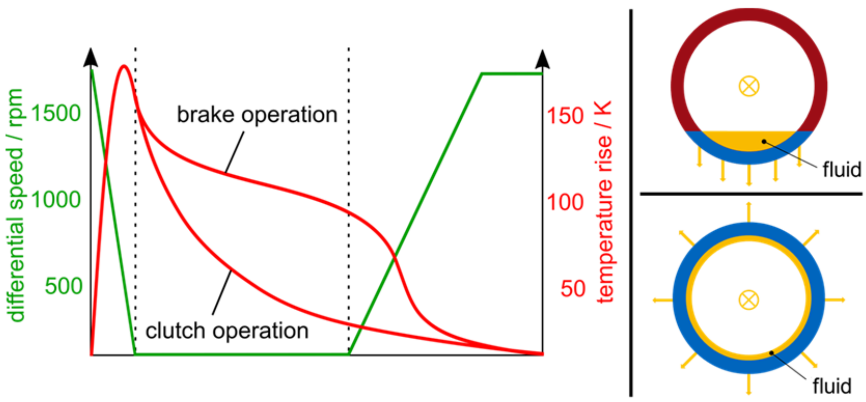

Figure 1: Shifting cycle with temperature curves for brake and clutch operation with schematic fluid distribution in the clutch

temperature curves for brake and clutch operation. Due to different distribution of the fluid during closed cooling phase, cooling performance strongly depends on operation mode.

Temperature measurements in the steel plate (center of clutch, average friction diameter; NiCr-Ni sheathed thermocouple ø 0.25 mm) show significant differences regarding cooling behavior of different groove patterns (waffle, grouped parallel, segmented) with otherwise constant operating conditions, clutch size and friction material (see Figure 2). Oil flow capacities through the closed clutch depend on operating conditions on the one side (here constant) and on geometry of the grooves on the other side.

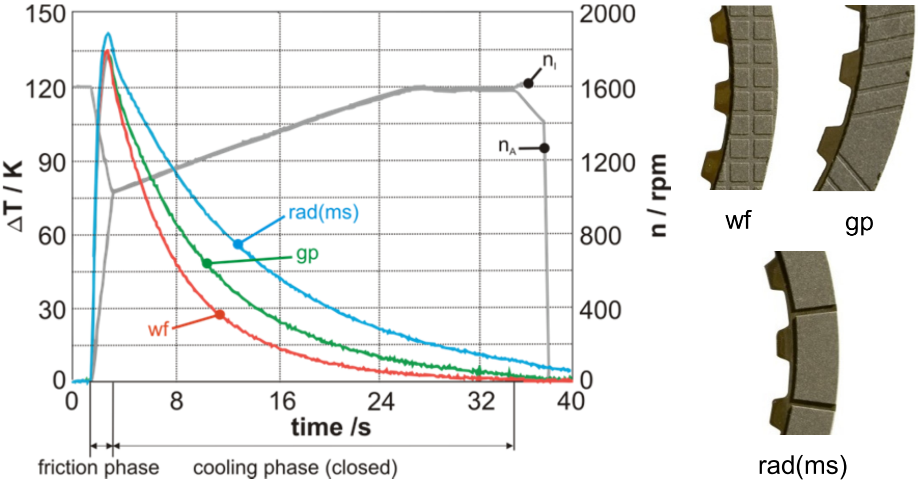

Figure 2: Temperature rise and cooling of clutches with different groove designs wf, gp and rad(ms) (measurements)

Oil flow capacity of a clutch is defined as the amount of cooling oil being transported through a closed clutch package at specific conditions and is therefore dependent on operation mode as well as number and kind of grooves in the friction material. For higher comparability all measurements are converted to reference conditions according to the table at the right. The equation describes the conversion of oil flow capacity to reference conditions being derived from investigations on laminar tube flow.

term	sign	unit	value
reference pressure	p	bar	0.5
reference oil temperature	ϑ	°C	80
oil density at 80°C	ρ	kg/dm^3	0.8
kinematic viscosity 80°C	ν	mm^2/s	8.5

$$\dot{V}_{reference} = \dot{V}_{measurement} \cdot \frac{\nu(\vartheta_{measurement})}{\nu(\vartheta_{reference})} \cdot \frac{p_{reference}}{p_{measurement}}$$

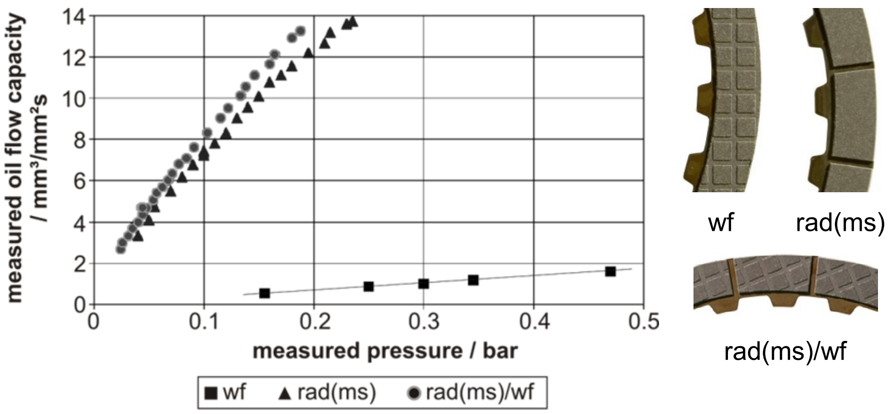

Figure 3: oil flow capacity – comparison of combined groove pattern rad(ms)/wf with basic groove patterns rad(ms) und wf

Various groove patterns may show significantly distinct oil flow capacities. Combined groove patterns being a superposition of two basic groove patterns show approximately summed up oil flow capacity of both basic groove patterns. Figure 3 shows measured oil flow capacity of basic groove patterns waffle (wf) and segmented (rad(ms)) as well as a measurement of the oil flow capacity of the combined groove pattern rad(ms)/wf. Measurement of oil flow capacity has been carried out in a static apparatus. Within this apparatus the clutch pack is located between two plates. A defined axial force F_{ax} is applied on the clutch pack and measured. Through an oil inlet, oil with a defined flow rate, pressure and temperature is supplied into the interior space of the clutch pack. A position sensor moreover allows measurement of the compressibility of the clutch plates.

THERMAL SIMULATION – FVA-PROGRAM KUPSIM

The FVA-program KUPSIM [6] realizes the calculation of thermal behavior of wet multi-disk clutches under specific load spectrums. Furthermore, KUPSIM supports dimensioning of wet multi-disk clutches. Besides the analysis of complete shifting cycles, the effects of cooling phases between shifting in a user-determined load profile on the thermal household of the clutch can be investigated.
Hereby, the temperature distribution of the clutch during friction phase and closed cooling phase can be calculated with two-dimensional spatial and timely resolution. Furthermore, the calculation of axial temperature distribution in the clutch disk package is implemented. Heat loss to the surrounding is modelled as heat transfer to the inner and outer catch as well as to the axial connecting parts. A different oil volume flow can be assigned for friction phase and cooling phase, both with open and closed clutch. Moreover, different heat transfer coefficients are provided in each phase for the oil flow through the clutch. An increased cooling effect in the lower part of the clutch being in brake operation is modeled with respect to the back oil effect during idle or ramp-up time. In clutch operation, the back oil ring formation is calculated. To display oil flow capacity correctly in thermal simulations, the equation explained above is implemented in the modeling of KUPSIM.
Figure 4 shows an exemplary thermal calculation result modeling a clutch with sinter friction material and six friction interfaces built up of four friction and three steel plates. The temperature field is displayed in axial and radial direction for a specific time step of calculation. Thermal symmetry allows calculation of only half the clutch package. Due to high thermal conductivity of the sinter material, a distinct heat transport in axial direction and into the connecting plate occurs. Peak temperatures occur at the friction interfaces.

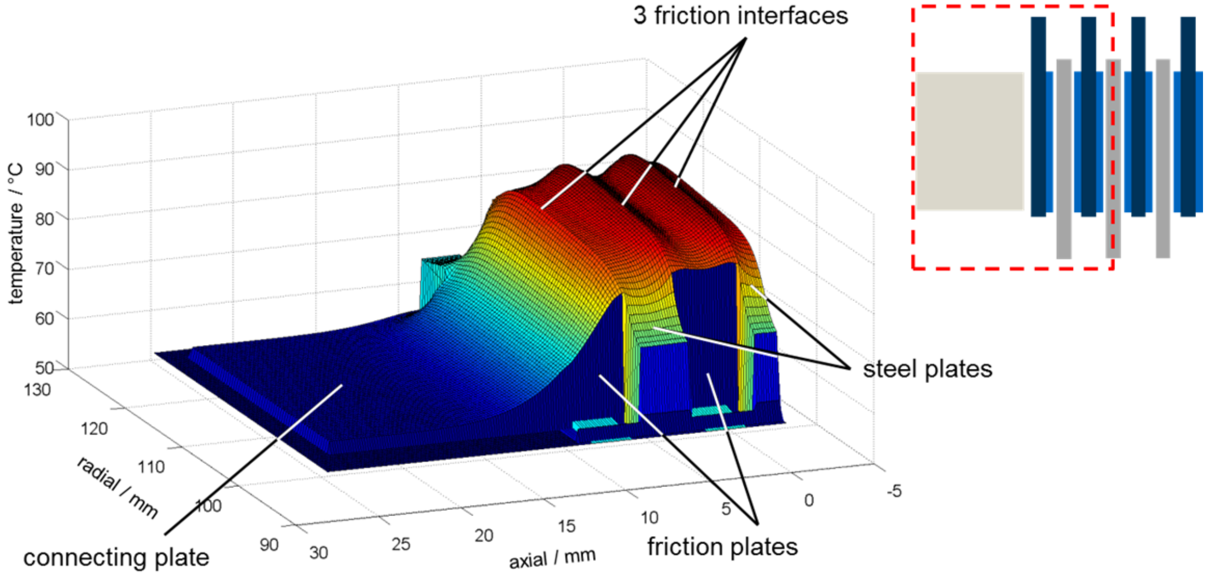

Figure 4: KUPSIM-calculation of the two-dimensional spatial resolved temperature field in a wet multi-plate clutch with sinter friction material

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KEYWORDS
Wet multi-plate clutch
Thermal Analysis