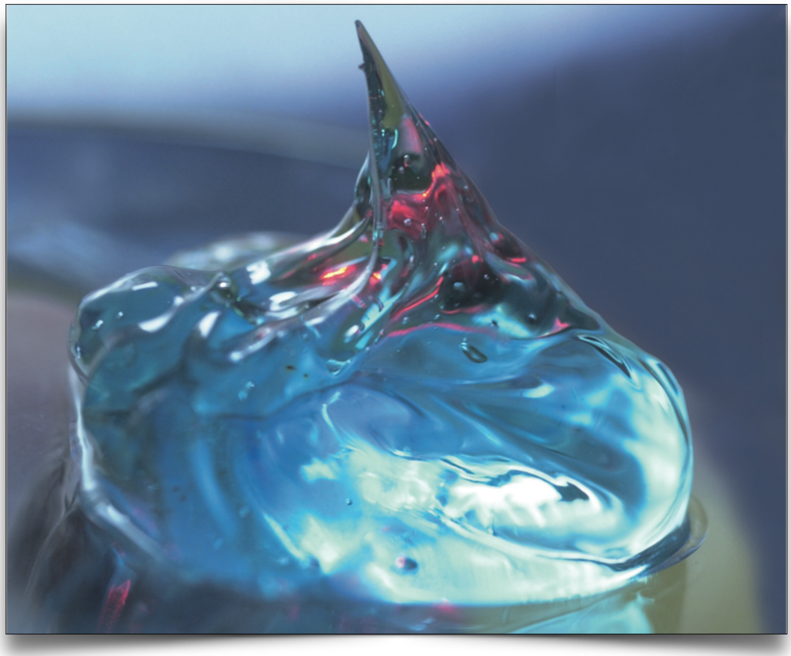
INTELLIGENT GEL SYSTEMS

BRIEF SUMMARY OF ADVANTAGES AND OPPORTUNITIES

"Commercial Vehicles"

November 2017



Dynamic Force Compensation

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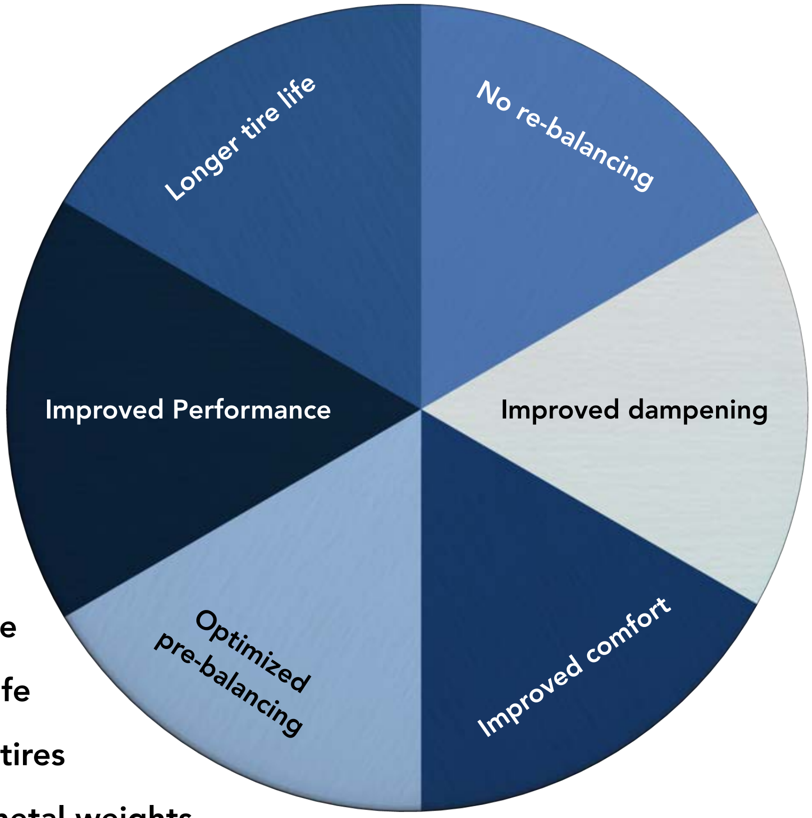
> **"Thixotropic gels with the characteristic of decreasing viscosity under accelerating loads/forces enabling automatic and continuous re-balancing of imbalanced loads in rotating machinery."**
>
> *- George David, former Chairman and CEO of United Technologies Corporation*

KEY ADVANTAGES

- **Noise reduction**
- **Lower production costs**
- **Optimized pre-balancing**
- **No re-balancing required**
- **Lower maintenance costs**
- **Improved driving comfort**
- **Reduction of CO_2 emissions**
- **Improved dampening behavior**
- **Improved on-road performance**
- **Improved balancing performance**
- **Less wear = longer equipment life**
- **Decrease of waste rubber - less tires**
- **Improved rim appearance - no metal weights**
- **Contribution to natural resources conservation**
- **Reduction of diffuse emissions of rubber particles**

Automotive wheels



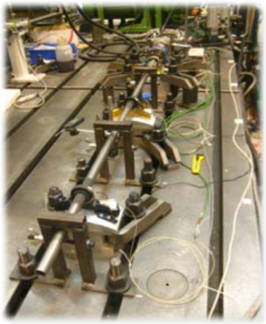
BACKGROUND - CONCEPT TO COMMERCIALIZATION

The concept of dynamic balancing was initially identified by Dr. Alvin Ronlán, a research scientist at the University of Lund Institute of Technology in the Sweden in the mid 1980's as a result of a research project, sponsored by Volvo at the Chalmers University of Technology in Sweden in 1982.

A number of renowned international scientists became associated with the project and the team came to include persons from the Faculty of Mechanical Engineers at Munich University of Applied Sciences in Germany, Université de Sherbrooke in Canada and the Natural Resources Management, University of Kalmar in Sweden. The members represented the highest standing in their respective fields of mechanical engineering, mathematics, chemistry, physics, environmental and the application of those disciplines to the automotive and tire industries and broader industrial applications.

The invention known as Dynamic Force Compensation or DFC is based on the discovery that viscoelastic (thixotropic) gels placed inside a cavity can act as a dynamic balancing agent capable of changing its shape and location in response to imbalance induced vibrations throughout the desired operational temperature range of $^{-}$40°C to $^{+}$120°C ($^{-}$40°F to $^{+}$250°F). The use of the technology will fundamentally reduce or eliminate balancing problems in a wide variety of industries. Virtually any object that rotates around an axle, such as tires/wheels, helicopter rotors, high-speed centrifuges, camshafts, turbines, fans, flywheels, wind turbines, washing machines, etc., can benefit using the DFC system.

Technical and commercial evaluations have been conducted in cooperation with world leading companies. The technology is protected by an extensive patent portfolio.

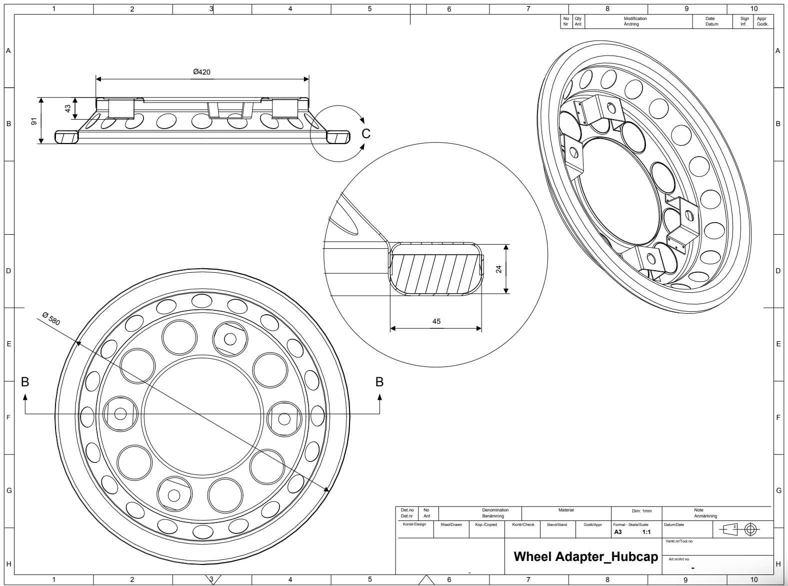


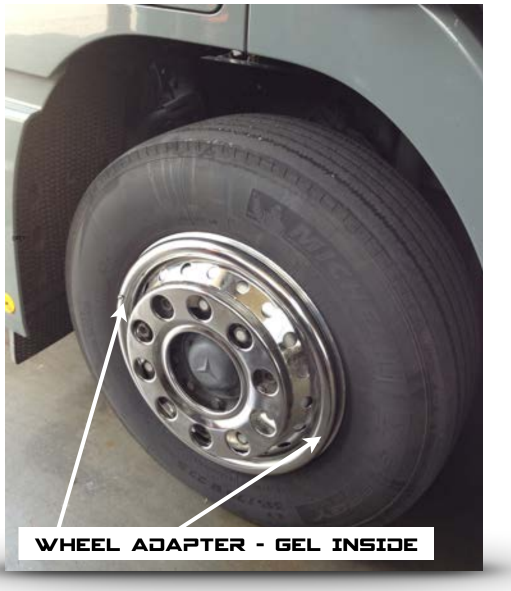
AFTERMARKET - COMMERCIAL VEHICLES

The initial marketing focus will be on the introduction of the DFC balancing system to the aftermarket for trucks and buses. “For most fleets, tire costs represent the second-highest operational cost category, exceeded only by fuel”[1]. The DFC technology offers substantial savings as a result of increased of tire life and by eliminating the costs and downtime associated with re-balancing.

Independent testing confirms that an increase of tire life of more than 50% can be achieved using the DFC system. A reduced requirement for the number of tires would also help lower CO_2 emissions related to tire production, diffuse emissions of rubber particles and metals from lost balancing weights and waste rubber from worn-out tires resulting from the estimated 250 million trucks in operation worldwide. It is further envisaged that an optimally balanced wheel will have a positive effect on noise, rolling resistance and fuel economy.

There is no complicated application method or training necessary to use the DFC balancing technology. The DFC Wheel Adapter is simply mounted to the wheel in the exact same manner that a traditional hubcap is attached.





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[1] *Tire PMs: Low-Tech Solutions for Cost Control, March 2017, Work Truck - Cover Story, Bob Stanton, CPM, CPFP*

SAVINGS ILLUSTRATION USING DFC WHEEL ADAPTER - TRUCKS/BUSES - US MARKET

Calculation of lifetime costs for a commercial vehicle tire

General assumptions:

INITIAL COST	SERVICE COSTS	AMOUNT ($)
(1) New tire		400
(2) Change of wheel (initial + seasonal)	10	
(3) Mounting of tire	10	
(4) Balancing of the wheel	12	
(5) Service time	30	
(6) DFC balancing wheel adapter (aftermarket price)		150

The average distance a tire is driven until it is “recut/retreaded” is approximately 200,000 km = the tire life of a metal balanced wheel, until it is retreaded, is approximately 400,000 km. Assuming a minimum of 25% extended tire life using DFC dynamic balancing, a tire will last 500,000 km. For this illustration and for easier comparison the below calculations have been based on a total driving distance of two million kilometers and the DFC Wheel Adapter having a minimum lifetime of five years. In summary, the estimated total operating cost relating to a commercial vehicle driven two million kilometers, using static balancing is $4,130 and using DFC dynamic balancing, $3,040, excluding any potential benefits relating to increased fuel efficiency.

Traditional static metal balancing:

INITIAL COST	AMOUNT (€)
Initial purchase 0 km (1+2+3+4+5), incl. 5 tires	2 310
60,000 km (2+4+5) x 5 cycles	260
120,000 km (2+4+5) x 5 cycles	260
180,000 km (2+4+5) x 5 cycles	260
240,000 km (2+4+5) x 5 cycles	260
300,000 km (2+4+5) x 5 cycles	260
360,000 km (2+4+5) x 5 cycles	260
400,000 km (2+4+5) x 5 cycles	260
TOTAL:	4 130

DFC dynamic balancing:

INITIAL COST	AMOUNT (€)
Initial purchase 0 km (1+2+3+5+6), incl. 4 tires and 2 adapters	2 460
60,000 km, 1/4 service time (5) for air pressure check only x 4 cycles	30
120,000 km, 1/4 service time (5) for air pressure check only x 4 cycles	30
180,000 km, 1/4 service time (5) for air pressure check only x 4 cycles	30
240,000 km (2+5) x 4 cycles	200
300,000 km, 1/4 service time (5) for air pressure check only x 4 cycles	30
360,000 km, 1/4 service time (5) for air pressure check only x 4 cycles	30
420,000 km, 1/4 service time (5) for air pressure check only x 4 cycles	30
500,000 km (2+5) x 4 cycles	200
TOTAL:	3 040

VALUE CREATION FOR CUSTOMER: WIN-WIN SCENARIO

The below assumes that on only the two front wheels fitted on the steering axle are balanced using DFC Wheel Adapters. Dynamic balancing is however beneficial for the remaining wheels, in particular unloaded trailer wheel.

Example, savings for fleet owners/operators: five year/two million kilometer cycle on 2 x wheels on steering axle:

DFC BALANCING ADAPTERS		TOTAL ($)	
Production cost: DFC Wheel adapter, incl. Gel		30	
Price per DFC Wheel Adapter		150	
Gross profit per unit (aftermarket)		**120**	
EXAMPLE: FLEET OWNERS/OPERATORS	**No. of trucks/ buses in fleet**	**x 2 tires**	**TOTAL GROSS PROFIT ($)**
Customer 1	1 000	2 000	240 000
Customer 2	2 500	5 000	600 000
Customer 3	5 000	10 000	1 200 000
Total: example three customers	8 500	17 000	2 040 000
SAVINGS: FLEET OWNERS/OPERATORS	**No of vehicles**	**savings per wheel ($)**	**TOTAL SAVINGS ($) per year**
Customer 1	1 000	1 090	**436 000**
Customer 1	2 500	1 090	**1 090 000**
Customer 3	5 000	1 090	**2 180 000**

Savings based on extended tire life (25%) ONLY:

SAVINGS: FLEET OWNERS/OPERATORS	No of vehicles	savings per tire ($)	TOTAL SAVINGS ($) tires
Customer 1	1 000	100	**100 000**
Customer 1	2 500	100	**250 000**
Customer 3	5 000	100	**500 000**

INTELLECTUAL PROPERTY RIGHTS

Breakthrough Innovation

The Dynamic Force Compensation technology was developed to alleviate problems associated with vibrations in objects rotating around an axle. Areas of application include, automotive wheels, washing machines, car drive axles, fans, power tools, rotors, train wheels, electro motors, turbines, plastic injection moulding machines and ship engine drives.

The advantages of the proprietary and patented DFC technology are based on improved functionality, cost reduction, safety and environmental benefits for manufacturers as well as end-users.

DFC is protected by a number of "patent families" with 10+ years of protection in key territories around the world.

OVERVIEW OF SUMMARIZED TEST RESULTS

Application	**Original Condition**	**DFC Condition**	**Improvement**
BBS (wheels)	0.0704 m/s^2	0.0111 m/s^2	84 %
Truck manufacturer* front right wheel 1	151,967 km	233,279 km**	35%[1]
Truck manufacturer* front right wheel 2	151,967 km	201,486 km**	27%[2]
Truck manufacturer* front right wheel 3	151,967 km	283,827 km**	46%[3]
Truck manufacturer* left front wheel 1	183,101 km	285,604 km**	36%[4]
Truck manufacturer* front left wheel 2	183,101 km	285,208 km**	36%[5]
Truck manufacturer* front left wheel 3	181,101 km	318,677 km**	43%[6]
Brose (fan)	0.195 m/s^2	0.087 m/s^2	55 %
Cardan drive shaft (GKN)	0.4 mm/s^2	0.32 m/s^2	20 %
BSH (washing machine)	10mm (critical) 5mm (supercritical)	8 mm 4 mm	20% 20%
Samsung (washing machine)	6 mm	3.3 mm	45 %
Deutsche Bahn (train wheel)	0.048 m/s^2	0.020 m/s^2	58 %
Eurocopter 2,500 rpm 66% DFC Gel filled	0.028 m/s^2	0.017 m/s^2	39 %
Eurocopter 3,750 rpm 66% DFC Gel filled	0.043 m/s^2	0.028 m/s^2	34 %
Eurocopter 5,000 rpm 66% DFC Gel filled	0.041 m/s^2	0.029 m/s^2	29 %
Arburg 200-400g	0.006 m/s^2	0.005 m/s^2	17 %
CEKA (juicer)	15.5 m/s^2	11.5 m/s^2	26 %
Kress (angle grinder)	4.9 m/s^2	3.7 m/s^2	25 %
Fan (household)	2.3 mm	1.3 mm	43 %
Chris Marine (grinding tool) 10g imbalance, 400g DFC	1.86 m/s^2	1.62 m/s^2	13 %
Chris Marine (grinding tool) 5g imbalance, 300g DFC	1.29 m/s^2	1.1 m/s^2	15 %
IRUS (power mower)	2.6 m/s^2	1.5 m/s^2	42 %

SUBJECT TO CONFIDENTIALITY

*****REPRESENTS EXTENDED TYRE LIFE AS FOLLOWS: [1]56%, [2]56%, [3]74%, [4]54%, [5]36% AND [6]87%.***

DYNAMIC FORCE COMPENSATION - TECHNOLOGY IN BRIEF

> *"Thixotropic gels with the characteristic of decreasing viscosity under accelerating loads/forces enabling automatic and continuous re-balancing of imbalanced loads in rotating machinery."*

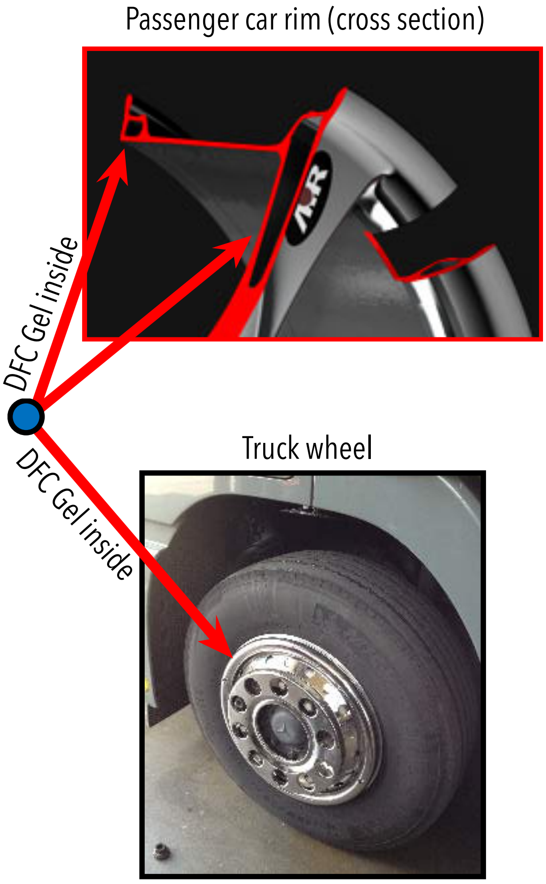
BACKGROUND

The Dynamic Force Compensation or "DFC" technology was developed to alleviate problems associated with vibrations in objects rotating around an axle. Applications include, but are in no way limited to, automotive wheels, washing machines, car drive axles, fans, power tools, rotors, train wheels, electro motors, turbines, plastic injection moulding machines and ship engine drives. The DFC Gel's functionality has been thoroughly tested and proven in collaboration with some of the world's leading companies.

What makes DFC unique are the particular properties that allows the Gel to migrate and redistribute under the action of stresses exerted upon them. These stresses are the result of centrifugal and lateral forces as well as impacts and vibrations created from virtually any source. An important consequence of the DFC Gel redistribution is that the amplitude of the vibrations, and associated energy dissipation, is considerably reduced.

Observations demonstrate that the thickness of the DFC Gel layer varies around the perimeter, which is contrary to the uniform gel spreading that would be the result where only the centrifugal forces determines the distribution. This confirms that the visco-elastic properties of the DFC Gels redistribute within a rotating object to minimise vibrational energy dissipation when subjected to influence of a combination of complex forces.

APPLICATION EXAMPLE



A typical wheel-tyre assembly exhibiting significant defects and vibrations is a complex situation. If the source of vibration is mass imbalance, one could envisage that free-flowing particles may distribute themselves to reduce imbalance and vibration. However, such redistribution is not an option for a Newtonian liquid; the required uneven distribution to compensate the mass imbalance would induce a large centrifugal stress even at moderate speeds. The fundamental characteristics of a Newtonian liquid is that it will flow in response to a stress, and will keep flowing as long as the stress is applied (the flow rate depends on viscosity, the higher the viscosity the slower the flow). Hence, liquids and freely movable powders cannot be expected to achieve effective balancing and vibration reduction. In addition, various other conditions of vibrations can arise, which freely-movable masses cannot alleviate. Ideally in order to minimize or eliminate vibrations in a rotating system a material is required that will change its location in response to vibrations from imbalances or other sources, but remain still in the absence of vibrations. Such materials are referred to as visco-elastic (or visco-plastic) gels.

As the name implies visco-elastic gels, depending on applied stress, can display both elastic and viscous behaviour, elastic: “solid-like” and viscous: “liquid-like”. In the absence of stress, they behave like solids (strain is linearly dependant on applied stress and deformation stops when an equilibrium state is achieved); when subjected to a stress above a certain value (critical yield stress) they behave like liquids. The response of a visco-elastic gels to an applied stress, also depends on the rate of application of the stress (frequency). At high frequencies, the gel will exhibit more elastic behaviour (solid-like properties); conversely, at low frequencies, the gel will behave as a viscous liquid.

In a tyre-wheel assembly subjected to vibrations from different sources, a visco-elastic gel behaves initially like an elastic solid when subjected to stress, as long as the stress is below the critical yield stress (CYS); it can also respond elastically to rapid accelerations, and therefore is not affected when the tyre hits a road bump or by the constant accelerations caused by contact with the road. When the CYS is exceeded, the visco-elastic gel can migrate slowly like a viscous liquid.

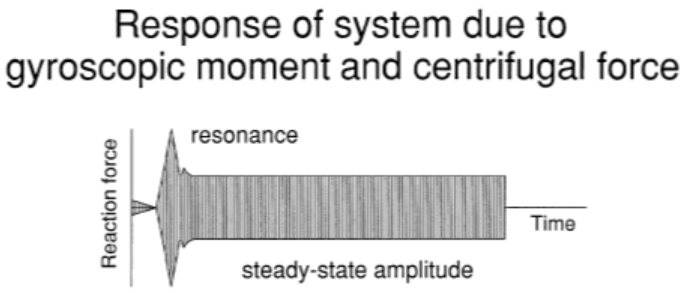
The actual mechanism causing the DFC Gel to be displaced in a manner to achieve optimal reduction of vibrations may be qualitatively described as follows. The initial gel displacements movements in the gel are caused by centrifugal and/or vibrational stresses exceeding the CYS value. Once in movement, additional forces may also act on the Gel due to motional or angular momentum coupling (e.g., Coriolis and gyroscopic forces). The DFC Gel will keep migrating under the combined influence of all forces identified above. The viscosity of the "gel in motion" is quite high; the DFC Gel will thus move slowly until it achieves a distribution where vibrations are highly reduced and no longer exert a sufficient stress to move the DFC Gel further. The DFC Gel will thus immobilise itself in this particular configuration, until vibrational or other stresses appear with magnitudes exceeding the Critical Yield Stress.

IN SUMMARY

A Visco-elastic gel can redistribute itself unevenly in response to vibrational stresses resulting from mass imbalance and other types of system defects, up to a point defined by the CYS and the induced centrifugal stress. DFC Gels have been developed and were designed with properties such that they will remain stable in the minimum vibration configuration. The above overall interpretation of DFC Gel function is consistent with observation that balancing occurs most efficiently at the resonance speed where the vibration forces are strongest.

MATHEMATICAL VERIFICATION

Extensive modelling has been carried out by experts to verify the subjective and objective testing of the Dynamic Force Compensation technology. Like all testing results, these findings are available for review.


Response of system due to gyroscopic moment and centrifugal force

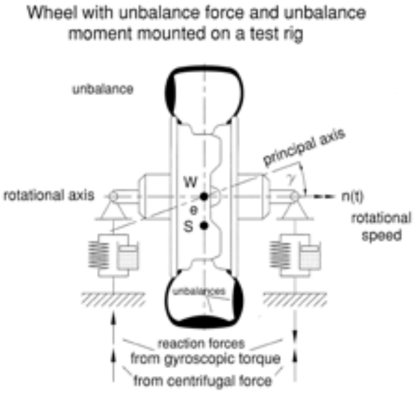
$$\boxed{M(t)\,\ddot{y} + D(t)\,\dot{y} + C(t)\,y + fz(t) = fr(t)}$$

$$\begin{bmatrix} m_{ges} & 0 & -m_R e\sin\varphi-\Theta_1 & -\Theta_1 & m_{FL}\cos\xi_k \\ 0 & m_{ges} & m_R e\cos\varphi+\Theta_2 & \Theta_2 & m_{FL}\sin\xi_k \\ -m_R e\sin\varphi-\Theta_1 & m_R e\cos\varphi+\Theta_2 & J^W+\Theta_3 & \Theta_3 & 0 \\ -\Theta_1 & \Theta_2 & \Theta_3 & \Theta_3 & 0 \\ m_{FL}\cos\xi_k & m_{FL}\sin\xi_k & 0 & 0 & m_{FL} \end{bmatrix} \begin{bmatrix} \ddot{x}_W \\ \ddot{y}_W \\ \ddot{\varphi} \\ \ddot{\psi}_k \\ \ddot{u}_k \end{bmatrix} + \qquad k = 1, \ldots, 2\,n_{FL}$$

$$\begin{bmatrix} d_{11} & d_{12} & 0 & r_t r_u\sin\xi_k & -r_r\cos\xi_k \\ d_{12} & d_{22} & 0 & -r_t r_u\cos\xi_k & -r_r\sin\xi_k \\ 0 & 0 & 0 & 0 & 0 \\ r_t r_u\sin\xi_k & -r_r\cos\xi_k & 0 & r_t r_u^2+\eta_k & 0 \\ -r_r\cos\xi_k & -r_r\sin\xi_k & 0 & 0 & r_r \end{bmatrix} \begin{bmatrix} \dot{x}_W \\ \dot{y}_W \\ \dot{\varphi} \\ \dot{\psi}_k \\ \dot{u}_k \end{bmatrix} + \begin{bmatrix} c_{11} & c_{12} & 0 & c_t r_u\sin\xi_k & -c_r\cos\xi_k \\ c_{12} & c_{22} & 0 & -c_t r_u\cos\xi_k & -c_r\sin\xi_k \\ 0 & 0 & 0 & 0 & 0 \\ c_t r_u\sin\xi_k & -c_r\cos\xi_k & 0 & c_t r_u^2 & 0 \\ -c_r\cos\xi_k & -c_r\sin\xi_k & 0 & 0 & c_r \end{bmatrix} \begin{bmatrix} x_W \\ y_W \\ \varphi \\ \psi_k \\ u_k \end{bmatrix}$$

Abbreviations :

$$\xi_k = \psi_k + \varphi \qquad \begin{aligned} d_{11} &= r_x + r_r\cos\xi_k^2 + r_t\sin\xi_k^2 & c_{11} &= c_x + c_r\cos\xi_k^2 + c_t\sin\xi_k^2 & \Theta_1 &= m_{FL}(r_u+u_k)\sin\xi_k \\ d_{22} &= r_y + r_r\sin\xi_k^2 + r_t\cos\xi_k^2 & c_{22} &= c_y + c_r\sin\xi_k^2 + c_t\cos\xi_k^2 & \Theta_2 &= m_{FL}(r_u+u_k)\cos\xi_k \\ d_{12} &= \tfrac{1}{2}(r_r - r_t)\sin 2\xi_k & c_{12} &= \tfrac{1}{2}(c_r - c_t)\sin 2\xi_k & \Theta_3 &= m_{FL}(r_u+u_k)^2 \end{aligned}$$


Wheel with unbalance force and unbalance moment mounted on a test rig