# Soft Yaw Drives for Wind Turbines

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## 1. Summary

Soft yaw drives have many advantages over conventional yaw (azimuth) drives for wind turbines. The need for yaw brakes disappears and the yawing moments generally decrease considerably. The introduction of damping is beneficial for the wind turbine system as a whole and is one way to deal with lateral tower oscillations and blade edge oscillations. Soft yaw drives are available as packages composed from standard components, which is beneficial for the life cycle cost of the wind turbine system, and have been certified by the main certification bodies.

## 2. Background

The general objective of a wind turbine yaw drive is to direct the wind turbine into the direction of the wind. The most common type of yaw mechanism is based on a rolling slewing bearing with a cogged inner or outer race and several pinions driven by electrical or hydraulic motors over high-reduction gearboxes. When not yawing the machinery is positively locked by means of several yaw brake callipers acting on a brake disc. Some of the callipers are activated also during yawing, in order to introduce damping into the system. Otherwise the cog play of the pinions will excite resonances, which was demonstrated by numerous failures of yaw drives during the early 80's. An early insight in the problems is presented in [1]. Examples of wind turbines operating with this type of yawing system are NEG Micon and Nordex.

Another common type of yaw mechanism is based on a friction bearing, which means that in principle no separate yaw brakes are needed. The friction has to be high enough to prevent motion during both operation and non-operation. Thus the torque rating of the yaw-drives has to be high, since they have to overcome both the friction and the yaw moment acting on the nacelle. Vestas and Tacke operate friction type yawing system.

## 3. Soft yaw drive with hydrodynamic coupling

A soft yaw drive has no yaw brakes. The nacelle of the wind turbine is free to rotate, although heavily damped, during all operational and non-operational events. The only exception is when, for maintenance purpose, the manual yaw-lock is activated.

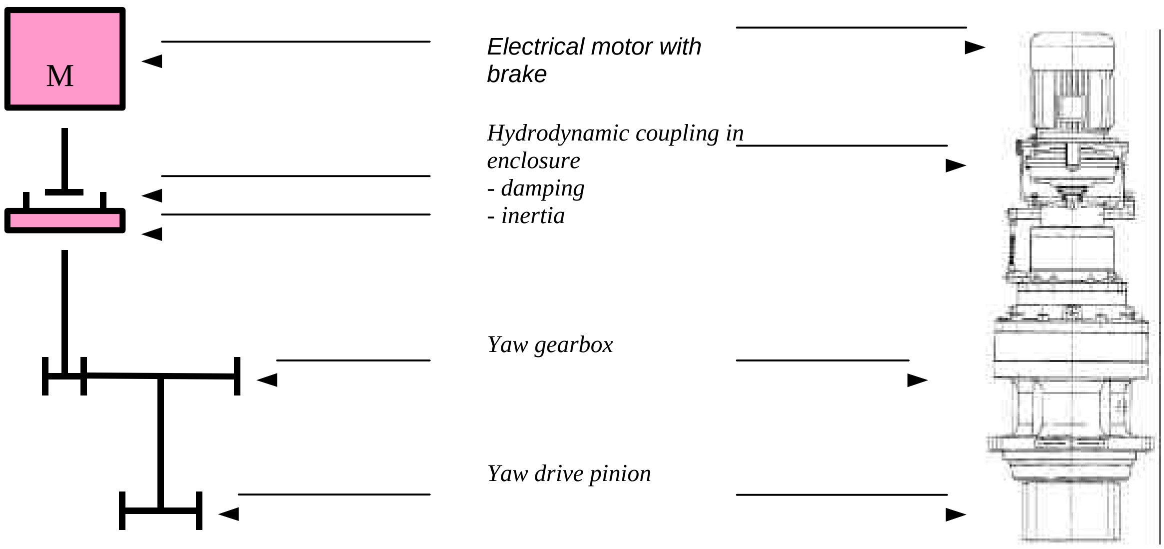


Fig. 1. Principle of a soft yaw drive.

The softness of the system is most easily accomplished by a hydrodynamic coupling that is inserted between the high-speed end of each yaw gearbox and its corresponding electrical motor, the latter furnished with a passive brake. See Fig. 1 and [2]. A hydrodynamic coupling is in principle a centrifugal pump fixed to the drive shaft, which is located in close proximity to an impeller, which is connected to the driven shaft, all within a closed housing. See Fig. 2 and Fig. 3.

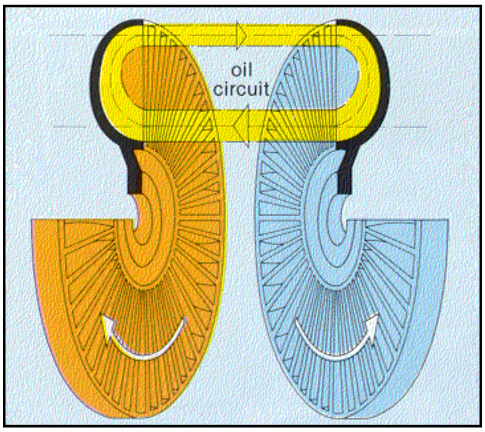


Fig. 2: Principle of hydrodynamic coupling. Sketch by courtesy of Voith.

The hydrodynamic coupling is characterised by the slip - in order to transfer torque, there has to be a certain speed difference between the driving and the driven wheels of the coupling. By definition, this slip is identical to damping, and thus damping is provided to the system during yawing.

The hydrodynamic couplings used are quite small, typical weight 5-10 kg. The damping effect acting on the wind turbine and nacelle is however increased by the yaw gear ratio squared. This means that a substantial amount of damping is introduced into the system.

When the wind turbine is not actively yawing, the electrical motor is braked by its passive brake. This means that also the corresponding side of the coupling is at standstill. The other side of the coupling is still free to rotate, although heavily damped due to the circulation of oil that this creates within the coupling. A hydrodynamic coupling can work continuously with one side stationary (in this application it is called a "retarder").

Thus, soft yaw drives provide damping both during yawing and non-yawing operation. The soft yaw drive is mostly combined with a yawing bearing of the rolling bearing type. It may also be combined with a friction bearing, which then preferably is selected with less friction than in ordinary applications. Soft yaw drives may be composed from stock components, including the slewing gearbox, the enclosed hydrodynamic coupling and the electrical motor.

Fig. 3: A soft yaw drive with a yaw gearbox, a hydrodynamic coupling in an enclosure and an electrical motor with a brake.

**4. Small yawing movements during operation**

A wind turbine rotor is exposed to a varying yawing torque due to the influence of both wind shear and turbulence. Due to the filtering effect of the rotor blades, the resulting yawing torque variations have prominent 3P or 2P elements, depending on the number of blades. With the soft yaw drive this results in a rocking motion of the nacelle, indicating that the varying yaw moment is absorbed as a damped motion rather than as pure torque. A typical amplitude of this motion during a high wind speed, high turbulence situation is ± 0.1 degrees, which is small, although enough to give a significant load alleviation. Besides the hydraulic damping effect of the coupling, also the inertial forces help to redistribute the energy flow and thus reduce the movements. In Fig. 1 the inertia is marked as a separate element, although it in reality appears in the coupling housing, when the coupling is oriented as indicated. In absolute terms the inertia of the coupling is small. However, in the same way as the damping, its effect on the system is increased by the yaw gear ratio squared. This means that it has about the same impact as the inertia of the nacelle and turbine combined. In fact, when designing the system one has to safeguard that the inertial effect of the coupling does not get too large, since it then will detoriate the intended performance.

## 5. The yawing error is reduced

In principle a soft yaw drive provides no stable yaw direction, at least if the wind turbine does not follow the wind direction by itself (passive yawing). In reality the strong damping applied, in combination with the stochastic wind direction variations, means that the amount of yawing time does not increase compared to a conventional yawing system. On the other hand, since yawing is provided much smoother, and due to the soft start and stop capability of the hydrodynamic coupling, one can use a yawing algoritm that provides more frequent yawings and thus decreases the mean yawing error, which has beneficial effects both on fatigue and on electricity production.

## 6. Effect on tower oscillations

In the first published description of a soft yaw system [3], the major benefit put forward was its ability to counteract lateral tower oscillations, also described as fish-tail oscillations (of the nacelle), which appear mainly as a result of an over-critical tower, an offset of the nacelle centre of gravity in relation to the tower and little aerodynamic damping in the lateral direction. With the sizes of today's commercial wind turbines approaching the scale that was demonstrated in the MW-turbines of the early 80's, the phenomenon of lateral tower oscillations again is raised as a problem that needs immediate action.

## 7. Effect on blade edge oscillations

Blade edge oscillations is a critical problem for many three-bladed wind turbines. The problem is hard to cure, partly because no torque component is introduced in the drive train, which in principle would be easy to handle. However, a component of the blade edge oscillations appears as a moment around the tower axis. This means that it in principle can be cured by damping the yaw drives, e.g. by the system with hydrodynamic couplings that is described in this paper.

## 8. Operational experience

The first soft yaw drive with a hydrodynamic coupling is in use in a Nordic 400 kW wind turbine since 1996, with 20000 hours of operation accumulated (end 2000). The only maintenance provided has been the exchange of a seal.

Soft yaw drives were demonstrated for the first time in the early 3 and 4 MW units of Swedyards and Hamilton Standard. Although not a commercial success, the 3 MW Maglarp turbine during ten years produced more electrical energy than any other wind turbine sofar (37919 MWh). These systems were based on conventional hydraulics with a high first cost, see [3]. The maintenance needed was considerable. However, they demonstrated, in the largest possible scale, that soft yaw systems are feasible. Similar systems are in use in WEG and Windmaster wind turbines. Soft yaw systems have been certified by the major certification bodies.

## 9. Implications for the yawing bearing

The small 2P or 3P oscillations have to be taken into account when selecting the yawing bearing that connects the nacelle with the tower. One effect of the small movements of the bearing rollers/balls is an increase of the local fatigue of the bearing race material, known as "brinelling". Another possible effect is reduced lubrication, since the movements may be too small to allow the balls to reach fresh grease. Experience has not revealed any increase in bearing cost or decrease in bearing life due to these implications.

A modification of the pinion lubrication may be necessary, since the frequent movements tend to remove the grease faster than in conventional yaw drives. The solution may be more frequent manual lubrication, change of type of grease or installation of automatic lubrication.

## 10. Torque limitation

During some extreme and rare load cases, e.g. a very rapid wind direction shift or very high turbulence or wind shear, the yaw torque may reach high values. The maximum torque that can be absorbed in a soft yaw drive is determined by the capacity of the holding brake of the electrical motor. A way to avoid excessive demand of the torque capacity is to accept slipping of this brake during the rare events, followed by an immediate shutdown. A small and well-protected detection device is an induction encoder that is inserted between the coupling and the motor.

**11. Conclusions**

- Low cost for installation and maintenance.
- Available as a package composed of stock components.
- No yaw brakes are needed.
- Lower rating of yaw drives.
- Less electricity used for yawing.
- Soft start and stop of yawing without noise.
- Small yawing error possible.
- Applicable with rolling and friction type bearings.
- Introduces damping in the wind turbine system, beneficial for counteracting instabilities such as lateral tower oscillations and blade edge oscillations.

**12. Literature**

[1] Jackson, K.L. Dynamic response of active yaw drives. Windpower ´88. September 18-22, 1988. Honolulu, Hawaii.
[2] Engström, Staffan. Yawing device and wind power plant comprising a yawing device. International publication published under the patent cooperation treaty (PCT), WO 97/42409.
[3] Doman, Glidden. Minimisation of the effects of yaw oscillations in wind turbines. European Patent application 83630181.2

# DEWI-Windenergie-Seminarprogramm 2001

## DEWI's Wind Energy Seminars 2001

Seifert, Henry; DEWI

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