Separating springs for active separation of the friction plates in wet clutch systems

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ABSTRACT

Efficiency losses are one of the main targets in the transmission development, especially in the view of the known CO$_2$-topic. If wet lamellar clutches are used as shifting elements the drag torque losses of the open clutches or brakes during shifting play a major role. Therefore, reduction in drag torque represents an important development target in recent research studies.

The use of waved friction discs or optimizing the friction pads show some results, but only an active separation of the lamellar discs exploits the whole potential. This separation is realized by new separating springs that are positioned between the lamellar friction discs.

To counteract against the contrary target of reducing system costs Mubea is purposing two approaches: On the one side the Mubea separating springs are designed to a very high level of load and stress, so that the function of the piston return spring can be taken over and that spring can be eliminated. On the other side the production costs of the springs can be reduced by using blanks out of wound and welded flat wire raw material.

By use of bench test investigations, the necessary requirements for these separating springs (for example the load tolerances with an optimum compromise between cost and function of each individual spring in the clutch) are evaluated and the effect on the drag torque reduction is measured.

1. Piston Return Springs in Automatic Transmissions

Both with classic automatic transmissions and modern dual clutch transmissions the switching elements take up a significant amount of the assembly space available and are therefore of interest to the design engineers. For a compact design, one of the few ways to save both radial and axial space is in the choice of piston return springs. Disc springs are used in modern automatic transmissions for piston return in the clutch. The essential advantages as opposed to conventional coil spring packs are the lower axial space required as well as great flexibility in the load curve. The saving in installation space often leads to a reduction in the overall system cost, resulting in further cost reduction potential.

Disc springs used for piston return require less axial space, so savings can be made both in the length of the clutch as well as the overall length of the transmission, if disc springs are included in the early development stages of the transmission. These benefits have been utilized in many transmission concepts in the past years already. The new approach of using separating springs that can inherit the function of piston return exploits additional potential for installation space savings by simultaneously improving the clutch efficiency due to a reduction of drag torque losses. As a further benefit there is the possibility to simplify the
clutch layout because the piston and balance dams do not need to be designed to interact with any return spring. Also, retaining rings or similar components might be designed out.

### Installation space

<table>
<thead>
<tr>
<th>Multcoil spring</th>
<th>Disc spring</th>
<th>Separating springs</th>
</tr>
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</table>

![Multcoil spring](image1)

![Disc spring](image2)

![Separating springs](image3)

**Drag torque reduction**

- ✓
- ✓
- ✓

**Figure 1: Piston return spring types and potential of axial space saving**

2. Drag Torque in Wet Clutches

The drag torque of a wet lamellar clutch depends on several influencing factors [1]. The two main of them are the relative revolutions and the revolution ratio between outer and inner friction discs. The corresponding drag torque diagram (Figure 2) shows the relative revolutions $n_{\text{relative}}$ on the x-axis and the revolution ratio $\lambda$ on the z-axis. Four characteristic areas are visible in this diagram:

- At low relative revolutions, (< 4000 rpm) the effect of the Newton’s friction plays the major role. Increasing revolutions account for rising drag torque.
- With increased relative revolutions, (approx. 4000 rpm to 5000 rpm) shares of air reach the areas between the friction discs. This effect causes a drop of the drag torque.
- In the range of approx. 5000 rpm to 9000 rpm the drag torque stays relatively stable.
- Beyond approx. 9000 rpm, the friction discs tend to wobble and get into contact to each other. This causes another increase of the drag torque at such high revolutions.

**Figure 2: Drag Torque losses in open wet clutches due to relative revolutions of inner and outer discs [1]**
The diagram shows that the highest drag torque losses occur in the range of lower relative revolutions (≤ 3000 rpm) and therefore the potential of drag torque reduction is at the highest level. This is the area where either one clutch runs most of the time in double clutch transmissions. Also, in step automatic transmissions, those clutches that are open most of the time could benefit from any drag torque reduction in a significant manner.

3. New Demands Regarding Function and Production Tolerances

The combination of the piston return spring function and the active separation of the friction plates leads to a number of specific demands that should be considered when designing clutches with these spring elements.

3.1 Comparison between disc type and wave type separating springs

In general, there are two different types of spring elements suitable for this application – the disc type or the wave type spring. The active load-creating principle differs from one spring type to the other. The disc spring creates the force by tangential elastic deformation of a dished steel ring, whereas, the waves of a wave type spring work like a double-sided clamped leaf spring. However, both springs can create rather high forces with a low material utilization. Both spring types typically create a linear load curve during stroking.

With respect to the application discussed in this paper there are some specific advantages of each spring type: The disc spring offers a very even load input to the contacting friction or steel discs. On the other hand, the even contact all over the circumference can prevent a sufficient oil flow to the lamellar discs mandatory for cooling. Depending on the required position of the separating springs, either on the inner or outer disc carrier and the designated oil flow, this can be compensated by features that improve the oil flow such as splines or holes.

By use of wave springs there is sufficient clearance in radial direction due to the wavy shape. Indeed, the following aspects have to be considered: Firstly, since the wave spring is not axially symmetric, in some applications an anti-rotation lock (e.g. splines) must be considered. Secondly, this spring type creates punctual contact spots in the wave peaks. These contact spots may lead to some undesirable wear on the friction plates. This can be optimized by some countermeasures (Figure 3): Wave springs in general generate the highest loads on the inner diameter (ID) due to the fact that the waves have a shorter period length. Therefore, this represents the most critical area. If flat wire as pre-material is used, this wire typically has a rectangular shape. During winding there will be a thickness increase at the ID due to compressing and a thickness decrease at the outer diameter (OD) due to stretching. This effect amplifies the effect of highest loads on the ID described before. In order to compensate this, Mubea can use raw material with a wedged shape in initial stage in order to achieve at least a rectangular shape after winding. Also, it is possible to exaggerate the wedge in order to create a larger thickness on the OD after winding to over-compensate the winding effect and additionally counteract against the effect of maximum loads on the ID.
A second option to reduce the wear problem is given by specific wave shapes. Mubea has some experience with flattened wave peaks that are able to distribute the necessary load over a larger area and therefore reduce the Hertzian Pressure.

![Wave Shapes](image)

a) Wedged flat wire pre-material  
b) Increased contact area on wave tops

*Figure 3: Potential countermeasures for wear optimization of wave springs*

### 3.2 High stresses due to high load requirements to be created by low material usage

Since the springs are positioned in parallel, each individual spring must accomplish the entire force required in order to return the piston while opening the clutch. This fact is even more challenging since the clutch layout usually offers only very little installation space for the springs, resulting in very small ring widths, typically < 5mm. On the other hand, the requested stroke can be divided by the number of spring elements used. However, calculation programs are used to predict the upper and lower stresses and corresponding pulsating stresses. Finally, specifically developed S/N-curves determine the durability that is achieved. The chance of failure is set to 0.1%. In addition, production tolerances and different surface treatments are considered. An attentive consideration of spline geometries is part of the design FMEA and additionally FEA calculations are performed on demand or in case of highly stressed spring layouts. Inner or outer splines might cause local stress risers, although, the overall stress distribution of the spring body is not critical.

The advanced Mubea single shot peening process (Figure 4) is specifically developed to improve the durability of sensitive springs. The equipment still works on the turning wheel principle; however each spring is guided individually through the ray-spot using constant parameters. This allows uniform surface treatment for each spring as well as consistent processing of a whole batch.

![Peening Process](image)

*Figure 4: The advanced Mubea single shot peening concept*
3.3 Tight load tolerances within one clutch to create uniform and constant distances between the friction plates

The main task of the separating springs is the active separation of the friction discs in an open wet clutch. It is possible to locate the springs either between the steel plates or the friction plates, although in this paper, mostly the friction plates are mentioned. The separating springs ensure a constant and widest distance between the surfaces, minimizing the drag torque resulting from the relative revolutions of the inner and outer discs.

It is expected that the effect of drag torque reduction is disturbed if some of the lamellar plates have a smaller or even almost no distance between each other. This happens in case of large load deviations between the separating springs. In a worst case scenario a spring with an upper limit load and one with a lower limit load could be located next to each other. Subsequently, the weak spring would be deflected by the strong spring and not separate the lamellar plates properly (Figure 5). Large deviations in the lamellar plate distances and subsequent higher drag torque losses would be the result. A high demand for tight load tolerances arises from this fact.

![Diagram showing load tolerances within one clutch](image)

**Figure 5: Tight load tolerances within one clutch to create uniform and constant distances between the friction plates**

In order to prove this theory, some benchmark tests by use of a real wet clutch have been performed.

A test bench for investigations of wet clutch systems has been set-up by the Institute for Product Development (IPEK) at the Karlsruhe Institute of Technology [2]. For realistic test conditions, an entire dual clutch has been selected and adapted to the test bench. However, all tests have been carried out with clutch K1. The equipment includes two independent dynamic servo-synchronous machines at the input and output side with about 125kW effective power and 3000 rpm each. The axial contact pressure of the friction partners is controlled by a hydraulic piston. The oil system that serves the lamellar disc pack consists of a lubrication oil unit with controllable oil temperature.

Besides other parameters the rotations of the disc carriers, the axial pressure in the hydraulic piston, the axial force, the torque, the temperature in the clutch pack, the oil temperature in the feeding and draining areas are measured and monitored.

Three different set-ups of separating springs have been tested: firstly, springs with nominal load and very tight deviations of less than ± 2% (best case), secondly springs with ± 5% load
deviations and thirdly springs with ± 10% (worst case) load deviations. Each test has been carried out twice. Figure 6 shows the measured drag torque during a simulated vehicle start at an oil temperature of 30°C and an oil flow volume of 20 l/min. It is visible that the best case spring set-up leads to a remaining drag torque of approx. 2 Nm from 2000 rpm on, whereas, the worst case set-up still creates a drag torque of more than 4 Nm.

Furthermore, tests have been carried out by varying the oil temperature as well as the oil flow volume. Higher oil temperatures basically lead to lower drag torque losses. The measured drag torque at 90°C was approx. half of the values measured at 30°C. Also lower oil flow volumes show the same effect. Tests with 1 l/min oil flow volume showed about 1 Nm less drag torque at low rpm, whereas, the difference became smaller with increasing rpm. At higher oil temperatures this oil flow volume effect becomes negligible – both the 30°C and 90°C tests show similar drag torque losses of approx. 2 Nm.

![Load tolerances: ± 2%, ± 5%, ± 10%](image)

**Figure 6: Drag torque at start** $[n_{out} = 0 \text{ rpm}, n_{in} = 0 \text{ to } 3000 \text{ rpm}, \text{oil temperature } 30^\circ \text{C}, \text{oil flow volume } 20 \text{ l/min}]$

Figure 7 shows the same general behaviour at different revolution ratios $\lambda$. The difference between the best case and worst case spring set-up again is in the range of 40%, furthermore the dependencies on the oil temperature and oil flow volume are principally similar.
Nevertheless, summarizing all these measurements it can be estimated that the drag torque can be reduced by up to 40% if springs with a low load deviation within the clutch are used in comparison to springs with a higher load deviation (Figure 8).

The overall drag torque reduction in comparison to a clutch without any active separation of the friction discs will be even larger. However, this could not been determined with the given test configuration. The drag torque reduction potential can be estimated to be in the range of 50% to 80% or with other words 5 Nm and more are realistic. Subsequently, the positive effect of the AT efficiency can result into a reduction of up to 2 gram CO$_2$, when the clutch operates in the high-drag-torque-range (depending on the transmission type and clutch layout).
4. Optimized Production Process

4.1 Cold forming or hot forming process?

Depending on the given application and concrete functional requirements there are different ways to produce ring shaped disc or wave springs. The choice of the material grade and the initial raw material condition represent the key success factors for the best result in the later application.

The most important difference in the production process is the decision if a hot forming process is mandatory or if cold forming is sufficient. Of course, the cold forming process involves much lower production cost in comparison to a hot die forming process.

Subsequently, the focus must be set to the material grade and initial microstructural condition. The choice of pre-hardened material, e.g. cold-worked by rolling or drawing, but also heat treated by continuous inductive hardening of the wire, has the potential to eliminate the heat treatment of the final work piece. On the other hand, it contains some restrictions regarding the functional targets of the spring. Heat treating with simultaneous hot forming with use of an alloyed spring steel, results in a superior tensile strength, \( R_m \approx 1500 \text{ MPa} \) by maintaining excellent ductility. Springs made out of cold-worked pre-material show a lower durability due to a limited ductibility and a larger set-loss when the tensile strength is restricted because of the needed deformation degree.

Also, the welding process must be taken into consideration because it leads to a reduction of tensile strength in the heat-affected zone and a very brittle area in the weld itself. Therefore, on disc type separating springs, a subsequent microstructural transformation is mandatory in order to avoid failures, whereas, on wave springs, there is the possibility to locate the heat-affected zone in a low-stressed area between the wave tops and bottoms. Another challenge of pre-hardened raw material is the more difficult adaption of arbitrary anti-rotation features such as spline geometries. The low tensile strength in the soft condition of spring steel (\( R_m < 650 \text{ MPa} \)) prior to the heat treatment, allows process steps like spline stamping in a much less problematic manner.

Finally, the specific application requirements must be evaluated carefully in order to decide which forming process represents the optimum between achievement of the functional targets and cost. Mubea offers adapted solutions for all applications with respect to both technological and commercial targets.

If heat treatment is required to meet high durability and low set-loss requirements, the tried and tested Mubea hardening concept, which has been used for years mostly for piston return springs in automatic transmissions, provides the best pre-conditions to avoid hardening distortions, which can occur during the quenching process. The result is more consistent geometric precision than with standard tempering processes. This is achieved by a process chain in which the austenitized hot springs are simultaneously quenched and coined (or waved) in a water-cooled tool. As opposed to tempering in a salt or oil bath, the springs cannot retract during the quenching process due the calibration in the tools. As discussed in chapter 3.3, the resulting high geometrical accuracy leads to a maximization of the desired drag torque reduction effect.
4.2 The Mubea welding process for separating springs

Regarding the welding process, Mubea undertook general investigations in cooperation with the Welding and Joining Institute (ISF) of the Technical University of Aachen. Several welding methods have been considered such as the laser welding or the resistance butt welding.

By reviewing the requirements, for the joining weld, one substantial criterion was the achievement of the durability targets that must be just as well as by use of fineblanked parts. In case of wave springs, there is a potential to locate the weld seam in the changeover between wave top and wave bottom that is characterized by reduced stresses. In case of disc springs, there is no such area with reduced stresses. In order to develop a welding process, that fits both wave and disc springs and after reviewing all benefits and disadvantages, Mubea finally decided to use the resistance butt welding to join the ring endings, including a subsequent weld seam finishing, in order to generate the final geometry.

The laser welding process has the advantage that it does not create a welding bead and consequently there is no bead that needs to be removed. The main disadvantage of laser welding is the fact that not the entire cross-section is fused together and that weld imperfections inside of the material can occur (Figure 9). These are difficult to detect, e.g. by ultrasonic sound. In contrast, the resistance butt welding process leads to a completely fused joining area without the risk of weld imperfections but requires a subsequent weld seam finishing due to the creation of a welding bead. Nevertheless, this welding process is the best solution in order to meet the target of an optimized durability of the later spring.
5. Cost structure

A high cost pressure arises from the fact that the separating springs are used multiply within one clutch. E.g. in dual clutch transmission a number of 10 separating springs is a typical value. Therefore the separating springs must provide a countable clear added value versus the on-cost. As discussed before, several potential approaches regarding function and production process are feasible and different transmission concepts with different target settings might lead to different approaches.

In order to compensate the on-cost of this higher number of spring elements, the raw material input must be optimized. So far, disc or wave springs for transmission applications have been fineblanked out of cold-rolled steel strip. The material utilization for the later spring in this case, is somewhere between 20 and 40% – the balance is scrapped. In case of the separating springs with very small ring widths, typically < 5mm, the material utilization of a square piece of steel strip would be less, in worst case below 10%. Therefore the use of flat wire for winding the ring is the right direction to go. The scrap share is reduced to < 5%, so almost the full amount of material is utilized.

Figure 10 shows a comparison between springs blanked out of steel strip and those wound of wire raw material. The cost benefit of the wire material rises significantly with increasing OD because the cost for the steel strip blank increase to the second, whereas, a few mm more length of a wire does not play a large role. Only on springs with very small diameters the slightly higher production cost that arise from the welding process counterbalance this material effect.

![Figure 10: Cost comparison of different raw material conditions](image)

In fact, the cost disadvantage of having more than one spring in the clutch cannot be completely compensated. On the credit side, there is the desired drag torque reduction resulting in higher transmission efficiency and a potential installation space saving resulting in lower package size and transmission weight. Both finally have the potential to lead to reduced system cost but definitely reduces CO₂ values and optimized performance. Finally, the customer must decide how valuable these benefits are in each specific transmission project.
6. Conclusion

If wet lamellar clutches are used as shifting elements, the drag torque losses of the open clutches or brakes during shifting play a major role and therefore represent an important development target in recent research studies.

An active separation of the lamellar disks exploits the whole potential. This separation is realized by separating springs that are positioned between the lamellar friction disks. These can be either disc or wave type springs. Mubea separating springs are designed to a very high level of load and stress, so that the function of the piston return spring can be taken over and that spring can be eliminated.

By use of test bench investigations the necessary spring requirements with respect to the load tolerances are evaluated and the effect on the drag torque reduction is measured. A drag torque reduction potential of up to 5 Nm is realistic by use of Mubea separating springs. To achieve this optimum, extremely tight load tolerances are mandatory. The positive effect of the AT efficiency can result into a reduction of up to 2 gram CO\textsubscript{2}, when the clutch operates in the high-drag-torque-range (depending on the transmission type and clutch layout).

The production costs of the springs can be reduced by using blanks out of wound and welded flat wire raw material and a subsequent high-quality weld seam finishing.

With worldwide engineering support and production experience of more than 400 million springs, Mubea is the right partner for transmission spring applications in future AT’s in general and highly stresses separating springs specifically.

List of references

[1] Information provided by the Institute of Automotive Engineering at the Technical University of Braunschweig, 2011

[2] Information provided by the Institute of Product Development at the Karlsruhe Institute of Technology, 2011