MAAG
ZURICH

DESIGN AND FUNCTION OF SYNCHRONOUS CLUTCH COUPLINGS

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1. Introduction

Most of the combined ship propulsion system require besides a Gearbox also clutches to connect or disconnect a prime mover to or from the propulsion shaft system. Several different types of clutches are known and can be succesfully applied to decouple shaft systems, they are shown in Fig. 1. Each one has its distinct advantages and disadvantages. For high power/speed applications the form-fit type clutches only can cope with operating conditions.

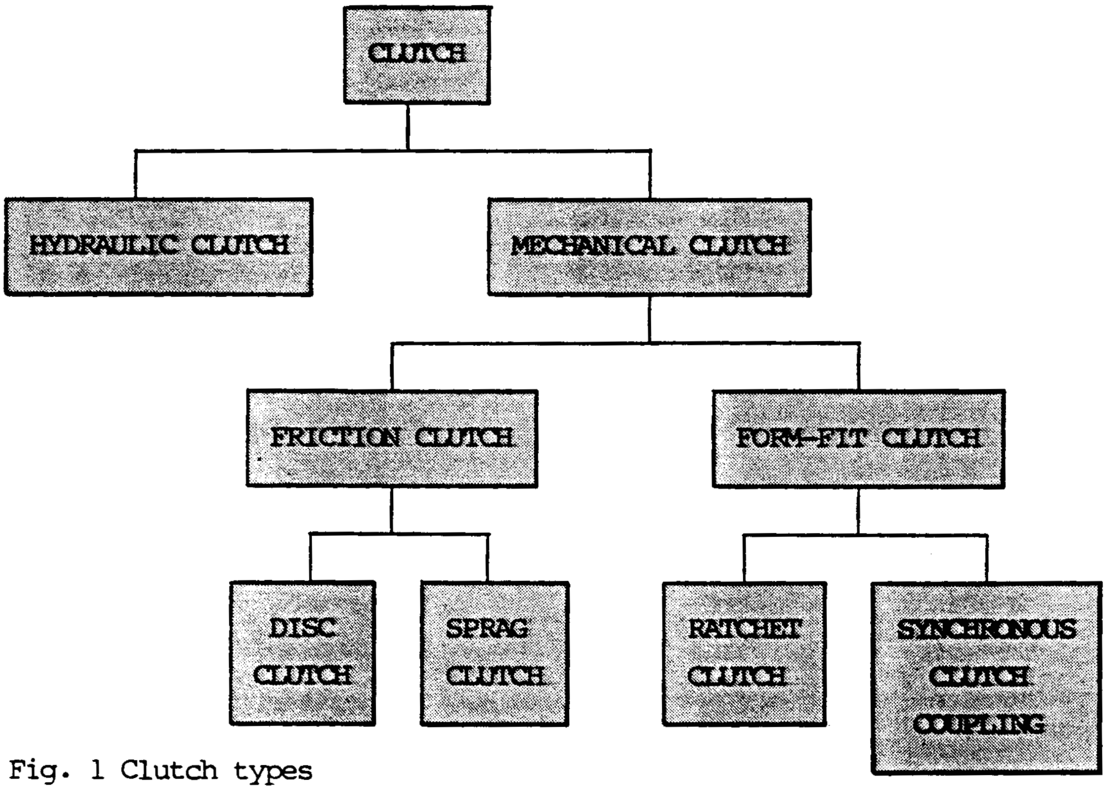

Fig. 1 Clutch types

Toothed couplings are form fit couplings. They are widely used in marine and land based machinery installations, because of their ability to transmit high torque at high speed and at the same time to accept misalignement and axial expansion of the coupled shafts.

The engineering task is to modify a toothed coupling such that it can be disengaged and re-engaged while the shafts are rotating.

Considering the high speed and high rate of acceleration and decelaration turbo machinery can achieve it is indispensable that the clutch-coupling functions mechanically and fully automatic. To disengage a toothed coupling presents no specific problem, however re-engaging the coupling is more difficult, because 2 conditions must be fullfilled by the shafts to be coupled:

1 - equal speed (synchronism)
2 - angular position (tooth aligned with tooth space)

The mechanism which can detect these conditions is a device consisting basically of a ratchet wheel and a number of pawls, see Fig. 2.

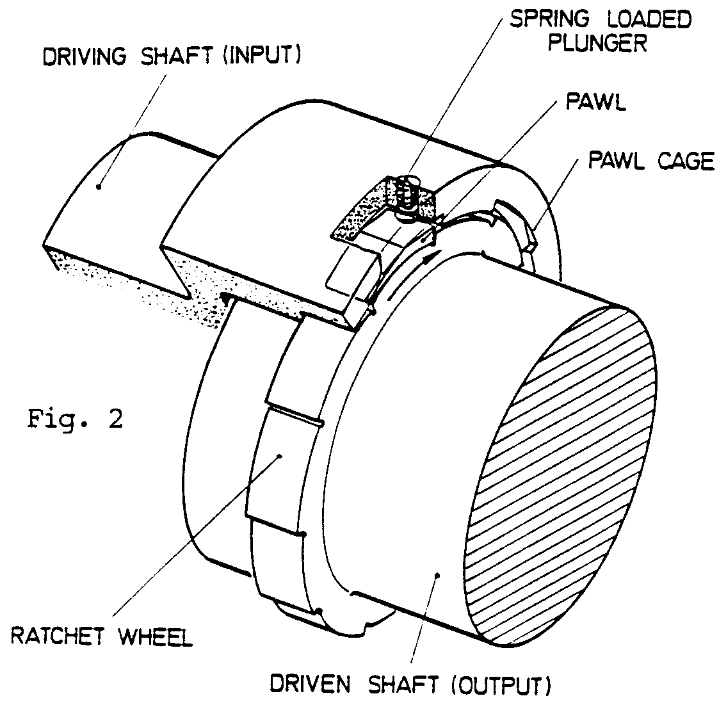

Fig. 2

This device, called "free-wheel" or "ratchet clutch" is known in engineering since many years and is used in many different types of machinery. It's most popular application is in the bycicle.

Placed between two shafts, acting as clutch, the free wheel allows one shaft (output side) to rotate free in one direction with the other shaft (input side) at standstill. By accelerating the input shaft it will eventually overrun the output shaft. At this instant a pawl will engage with a ratchet tooth. Synchronism of the shaft is thereby achieved (condition 1) and a torque may be transmitted. With a free-wheel having only one pawl and one ratchet tooth, the relative angular position of input and output shaft at synchronism would be identical at each engagement (condition 2). A free-wheel having for example 6 pawls and 11 ratchet teeth has 66 possible engagement positions (for an engagement one pawl only engages with a ratchet tooth) and is therefore suitable to align a toothed coupling having 66 teeth. The free-wheel device is the ideal synchronizing mechanism permitting a positive engagement of the toothed coupling. The combination of a toothed coupling capable of transmitting high torques, with the free-wheel as synchronizing mechanism form the Synchronous Clutch Coupling.

2. Description of the Synchronous Clutch Coupling

2.1 Basic Design and Function

To engage a toothed coupling one set of teeth has to be moved axially relative to the mating teeth, this movement has to be initiated by the synchronizing mechanism when a pawl is in contact with a ratchet tooth. To achieve this, the basic free-wheel, see Fig. 2, is modified by separating the ratchet teeth from the output shaft. A ratchet wheel is created which is supported on the output shaft and is connected to it by synchronizer splines (helical splines), see Fig. 3.

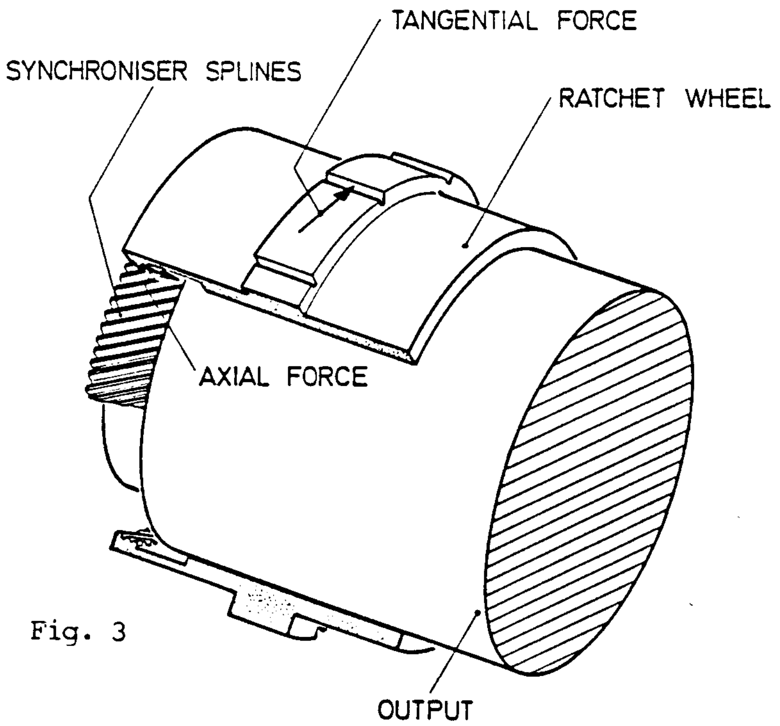

Fig. 3

When a pawl is acting on the ratchet wheel, it performs a screw motion relative to the output shaft governed by the synchronizer splines.

Around the ratchet wheel a clutch hub is arranged in which the pawls are located, see Fig. 4.

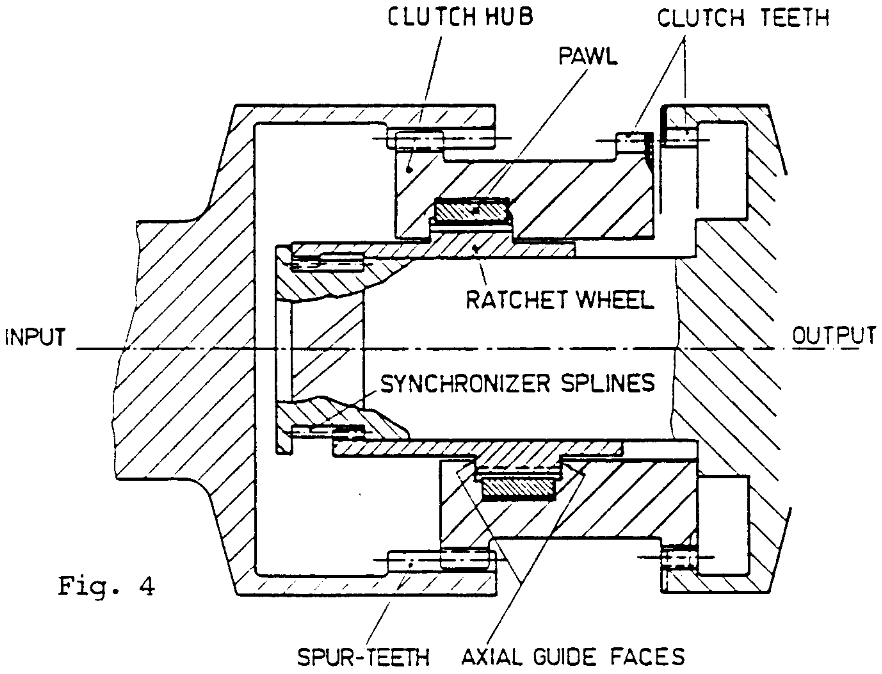

Fig. 4

The clutch hub being guided in axial direction by guide faces which are in contact with the ratchet wheel, follows any axial movement which the ratchet wheel performs (and vice versa).

The input shaft is connected to the clutch hub via straight splines allowing the axial movement. The external and internal clutch teeth to be engaged are arranged on the clutch hub and on the output shaft respectively.

It is assumed that the output shaft together with the ratchet wheel is rotating and that the input shaft, clutch hub and pawls are at standstill. By accelerating the input shaft it will eventually overrun the output shaft, and thereby bringing a pawl into contact with a ratchet tooth. Part of the accelerating torque developped by the driving machine (input shaft) is now transmitted by the pawl to the ratchet wheel and via the synchronizer splines to the output shaft (driven machine). The transmitted torque will generate an axial force in the synchronizer splines which initiates the screw movement of the ratchet wheel and clutch hub relative to the output shaft. The clutch teeth arranged on the clutch hub are brought into engagement with the teeth on the output shaft by the screw movement which the clutch hub performs. The teeth are champfered giving ample clearance for engagement. The clutch teeth are making contact because their helix angle is smaller than the helix angle of the screw movement performed by the clutch hub. The synchronizing phase is concluded when the flanks of the clutch teeth make contact, as shown in Fig. 5.

The accelerating torque having been transmitted by the pawls during the synchronizing phase is now transmitted by the clutch teeth. Being helical teeth an axial force is generated which takes care of continuing the axial movement until the clutch teeth are fully engaged. The clutch hub abuts on the output shaft, thus concluding the engagement phase. The pawl having been in contact is unloaded during the engaging phase due to relative tangential movement between pawl and ratchet tooth, resulting from two different screw movements performed by the clutch hub and the ratchet wheel. The relative tangential movement, resulting in a gap between pawl and ratchet tooth, occurs because the ratchet wheel, guided by the synchronizer splines having a large helix angle, travels over a large tangential distance, whereas the clutch hub and pawl, guided by the clutch teeth having a smaller helix angle, travel over a shorter tangential distance, see Fig. 6 (plan view).

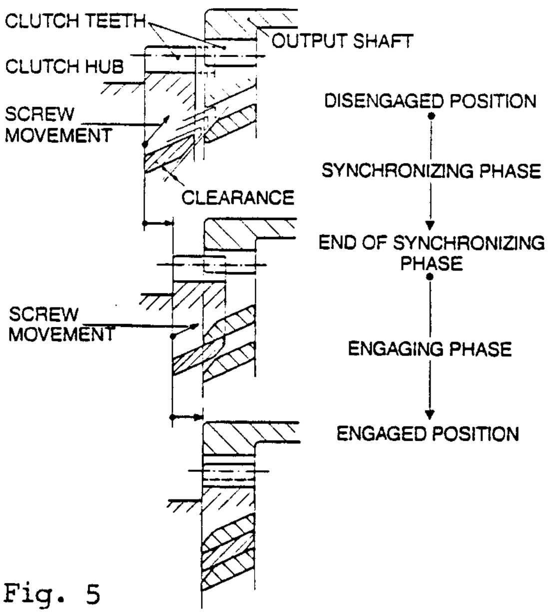

Fig. 5

With the clutch fully engaged the rated torque can be immediately transmitted. The only elements loaded by the torque are the straight splines an the clutch teeth. The synchronizing components, such as pawls, ratchet wheel and synchronizer splines do not take part in transmitting the torque, since the pawl is no longer in contact with the ratchet tooth.

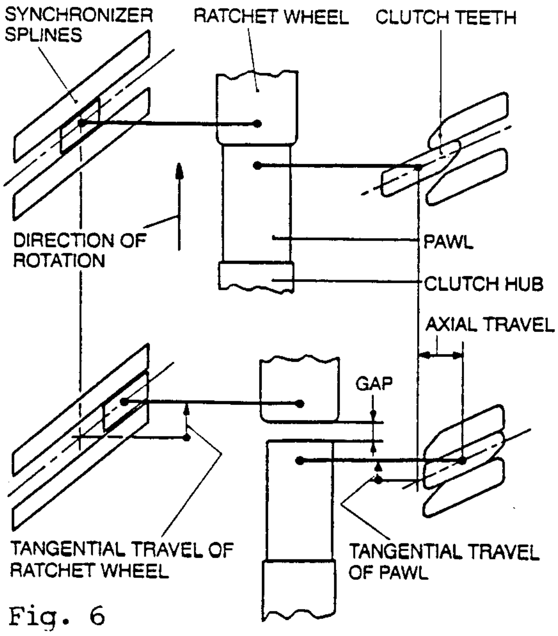

Fig. 6

The clutch remains engaged as long as torque is transmitted from the input- to the output shaft. When the torque reverses, i.e. a torque is transmitted from the output- to the input shaft, the axial force generated in the clutch teeth reverses thus causing the clutch to disengage.

The engaging clutch teeth can also be made as straight teeth. The consequence is that at the end of the synchronizing phase the continuation of the axial movement to fully engage the clutch can not be activated by the clutch teeth because no axial force is generated in straight teeth. To conclude the clutch engagement an external force is required. A stationary hydro-mechanic power unit, which is connected to the clutch hub by means of an axial guide ring and a lever, forces the clutch into full engagement. The power unit is self controlled and applies the high axial force just before the synchronizing phase is concluded, see Fig. 7. During the synchronizing phase a small external force only is acting on the clutch hub.

The fully engaged clutch can transmit torque in any direction, i.e. from input- to output shaft and vice versa. To disengage the clutch a signal is given by an external machinery control unit to the hydromechanic power unit causing it to reverse the axial force thereby disengaging the clutch.

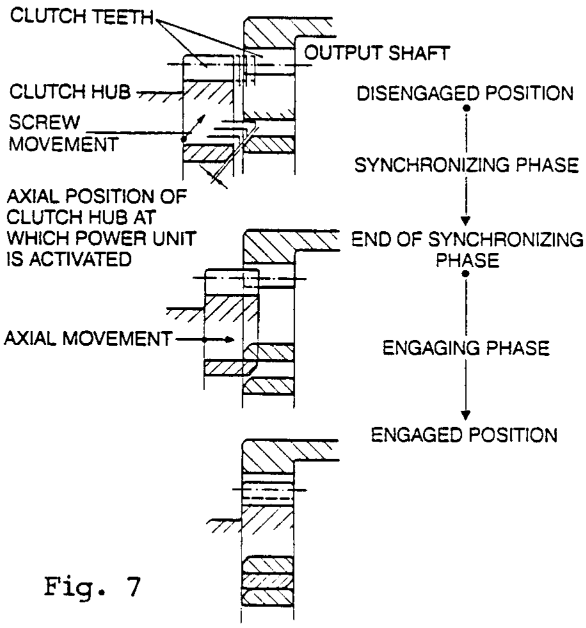

Fig. 7

To distinguish between the two different working principles the following type designation are used:

MS for a clutch having helical clutch teeth
HS for a clutch having straight clutch teeth

The above described working sequences show clearly the simplicity of the principle, and the small number of vital components involved. However for a clutch to perform flawless under realistic operating requirements some more refinements in the design, as discribed in the following paragraphs, have to be incorporated.

2.2 Synchronizing Components

With disengaged clutch the output shaft and the ratchet wheel may rotate at high speed whereas the input shaft with the pawls are at standstill. The contact faces of ratchet wheel and pawls are lubricated by injected lube oil. Due to the relative speed and the suitable shape of these components, see Fig. 8, a hydrodynamic oil film between pawls and ratchet teeth is generated preventing metallic contact. The MAAG clutch can therefore run in disengaged condition for unlimited time even at low differential speeds.

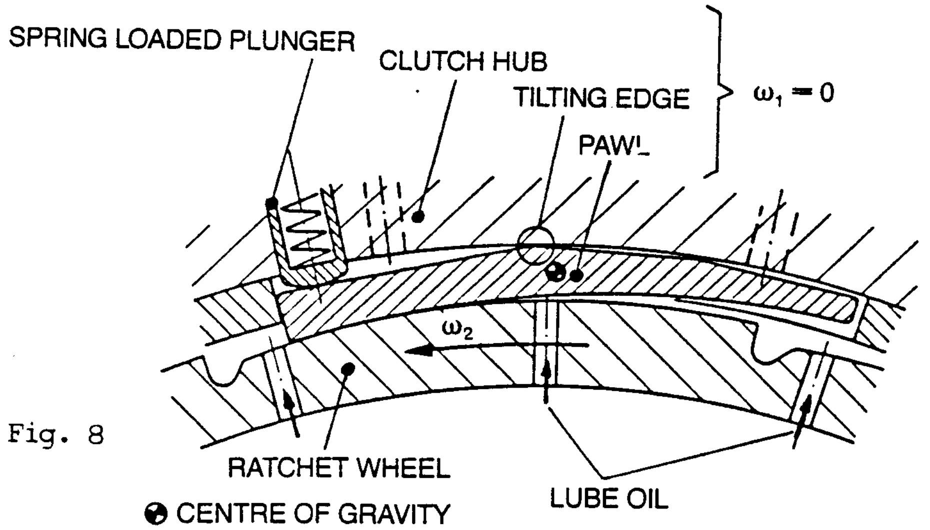

Fig. 8

The pawls, located with ample clearance in cages formed by two rings thus avoiding the use of locating pins, are completely free to move. A tilting edge on the outer contour and the tail-haevyness of the pawl insure that the nose is lightly pressed on to the ratched wheel and that it contacts the ratchet tooth correctly when the input shaft overruns the output shaft.

With disengaged clutch and both shafts, input and output, at standstill the initiation of the synchronizing phase occurs by starting-up the input shaft. In the absence of the centrifugal force a spring loaded plunger is acting on each pawl insuring the contact between pawl and ratchet wheel. Due to the fact that no relative axial movement between pawl nose and ratchet tooth takes place during engagement no wear occurs on these surfaces.

Particularly important in that respect is that the unloading of the pawl during the engagement phase is in tangential and not in axial direction, thus avoiding corner loading.

2.3 Shock Absorber

The angular positions of the pawls relative to the ratchet wheel teeth at exact synchronism are at random. The input shaft, still accelerating, overruns the output shaft, bringing thus the pawls towards the ratchet teeth. When the pawl nearest to a ratchet tooth hits it, the mass of the clutch hub has to be instantaneously accelerated, which leads to a high load on the pawl. To limit this load, pre-stressed springs are arranged axially between the ratchet wheel and the clutch hub, see Fig. 9.

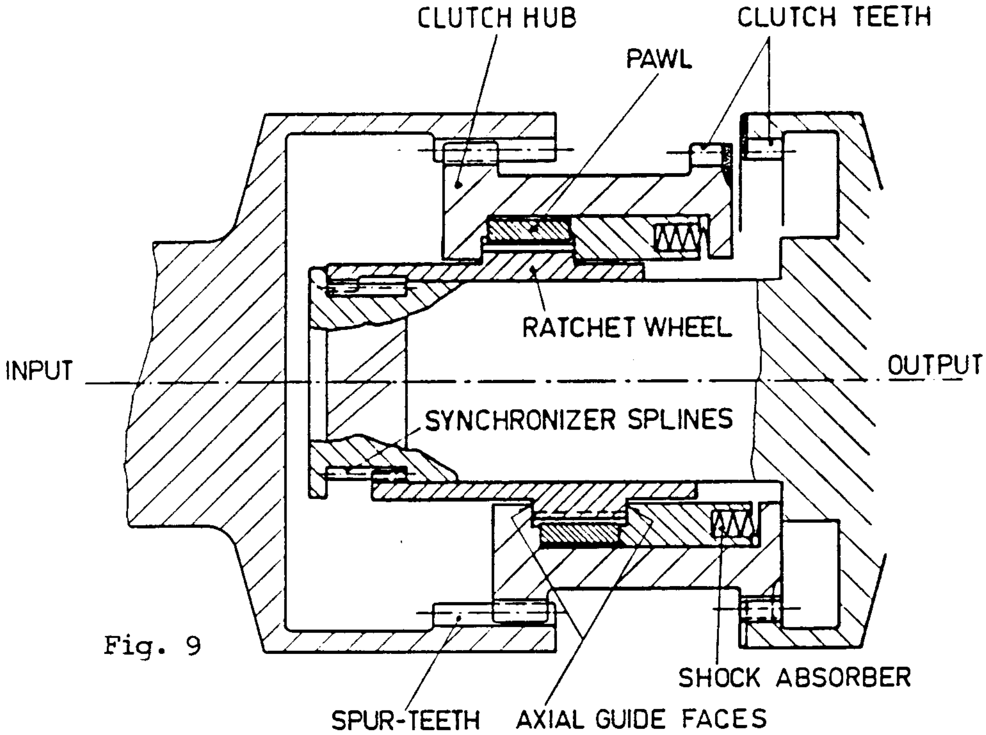

Fig. 9

The effect is that the pawl load is then mainly determined by a spring- and not by a mass-force. The clutch hub is accelerated in axial direction by the spring force. The spring characteristics and the pawl load are computed considering:

- relative angular acceleration
- overrunning angle
- mass of pawl carrier
- axial travel of pawl carrier during synchronizing phase
- friction in clutch

The shock absorber permits to engage the clutch at high angular accelerations.

Typical accelerations of turbines are:

1000 RPM/sec (small power)
500 RPM/sec (medium power, i.e. 20 MW at 3600 RPM)
100 RPM/sec (high power)

It must be noted that the clutches equipped with a shock absorber can easily cope with these values. If the synchronization takes place while the output shaft is decelerating, the clutch has to sustain a relative acceleration which is equal to the sum of acceleration of the input shaft and the deceleration of the output shaft.

2.4 Toothed Coupling

The engaging helical clutch teeth of the MS-clutch are tightening the clutch hub to the output shaft when the clutch is transmitting a torque. The axial force generated in the clutch teeth is taken up by the abutment, therfore no force is acting on the output shaft. This tightened mesh of the clutch teeth can not operate as coupling teeth. The straight splines however can accept angular misalignement. To have a fully flexible coupling a second straight tooth mesh is added on the clutch hub, Fig. 10 is showing this arrangement. The coupling sleeve, axially located at the input side mesh, is connecting the two shafts and it allows for any possible misalignment.

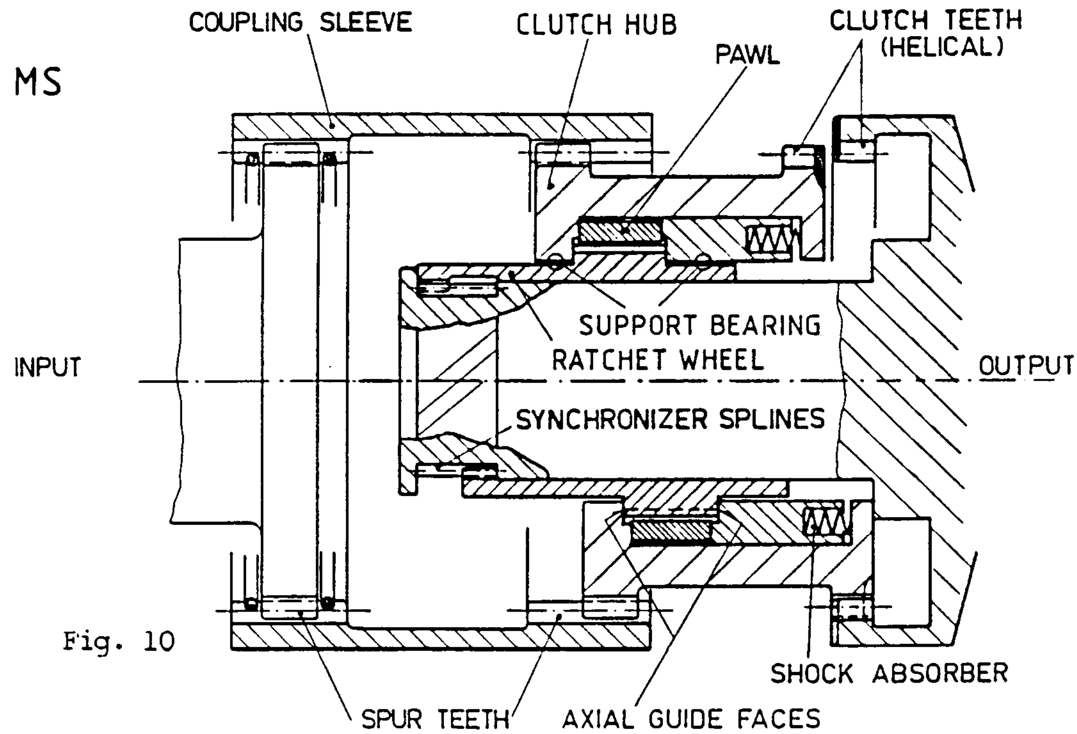

Fig. 10

The straight teeth of the HS-clutch can operate as coupling teeth, together with the straight splines they form a double engagement toothed coupling, see Fig. 11.

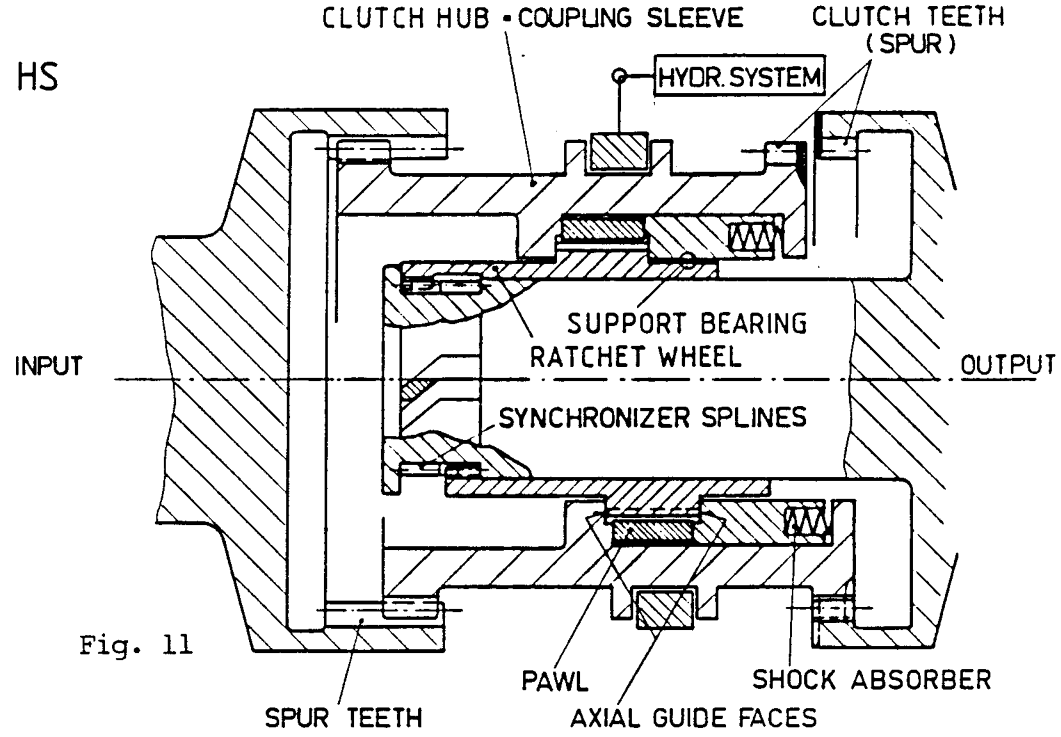

Fig. 11

2.5 Support Bearing

When the clutch is engaged all components rotate. The floating coupling member is supported by the coupling teeth. After disengagement of the clutch the input shaft with all clutch components connected to it comes to standstill. The supporting action of the teeth on the output side is no longer effective. An internal support bearing, designed as hydrodynamic sleeve bearing, is placed in the clutch hub, see Fig. 10, 11. The support bearing is designed to carry the weight of the input clutch members and to operate at the full speed difference of the shafts. Due to friction in the support bearing and associated axial guide bearing, arranged around the ratched wheel, a small drag torque is transmitted from the output shaft to the input shaft. For the clutch this drag torque is a negative torque and because it is transmitted via the synchronizer splines a small axial force is generated acting in disengaging direction. This force keeps the clutch positively disengaged.

2.6 Dashpot

The MS-clutch incorporates a dash pot which reduces the impact at the end of the engagement phase, when the clutch hub abuts the output shaft, Fig. 10. It is a small ring cylinder which is formed by the ratchet wheel and output shaft. Lube oil is constantly fed to the dash pot, the damping is effected by squeezing out the catched oil through a small hole.

The HS-clutch incorporates a dash pot in the hydro-mechanic power unit. The function is basically identical to the MS-clutch dash pot.

2.7 Lubrication

Lube oil is injected into the clutch hub to lubricate all the components, which are subjected to relative movement when the clutch is disengaged, such as support bearing, axial guide bearing, ratchet wheel and pawls. Lube oil is also supplied to the coupling teeth since relative movement exists between the tooth flanks when the clutch coupling is engaged and is operating with misaligned shafts.

2.8 Controls

The expenditure on controls for a clutch is minimal and depends largely on the operating requirements. The MS-clutch basically needs no control at all, it can be equipped with limit switches or proximity probes to indicate the clutch position. The HS-clutch needs two external signals, one to prepare the hydro-mechanic power unit for engagement, the other to disengage the clutch. The position signals are used for indication and/or interlocks.

The clutch is an overrunning clutch, therefore the speed control of the prime mover must be set in such a way, that the drive unit tries to exceed the speed of the driven equipment, with a reasonable acceleration. This overrunning initiates the engagement of the clutch. The engagement will not take place when by the control system of the driving machine equal speed of the two shaft systems is attempted.

Both, the MS- and HS-clutch, allow the continuous operation at relatively small speed difference. As a rough guide the minimum differential speed for continuous operation may be assumed to be 10% of max. nominal operating speed the clutch has been designed for. Due to the correct shape of the synchronizing components and the positive lubrication no wear will occur in the clutch, see Photograph 12, 13.

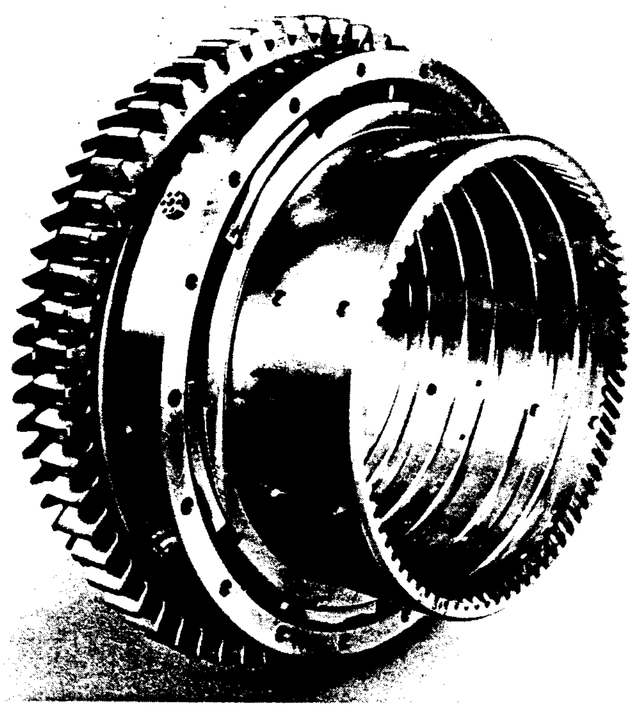

Fig. 12

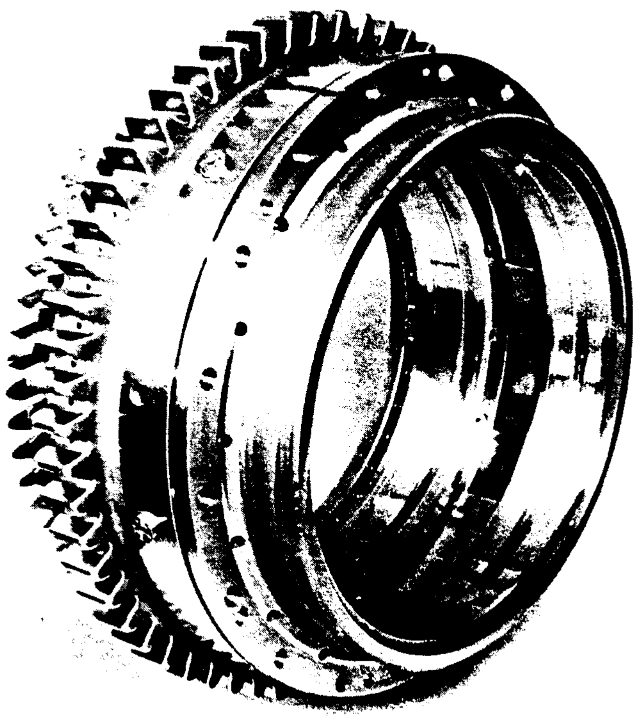

Fig. 13

3. Isolating Device for "pawl free" Operation

3.1 Basic Design and Function

Both types of clutches (MS and HS) can be equipped with an isolating device to operate the driving machinery independently from the shaft system ("pawl free" operation).

By shifting the coupling sleeve in axial direction the teeth at the input side are disengaged which allows rotation of the input shaft in any direction and at any speed. When disengaged, the coupling sleeve is supported at the input side in the casing. A simple static support is provided when the output components are at standstill during the "pawl free" operation of the driver. The support is designed as hydro-dynamic bearing if it is an operational requirement that the output shafts rotate during "pawl free" operation of the driver. After concluding the "pawl free" operation, the coupling sleeve is shifted back to the engaged position, restoring the clutch into its normal operating condition.

3.2 Local and Manual Operation

In most applications it is sufficient to operate the isolating device manually at the clutch location. The MS-clutch therefore provided with a device consisting of a hand lever, axial locating bearing and a spring loaded positioning mechanism, see Fig. 14.

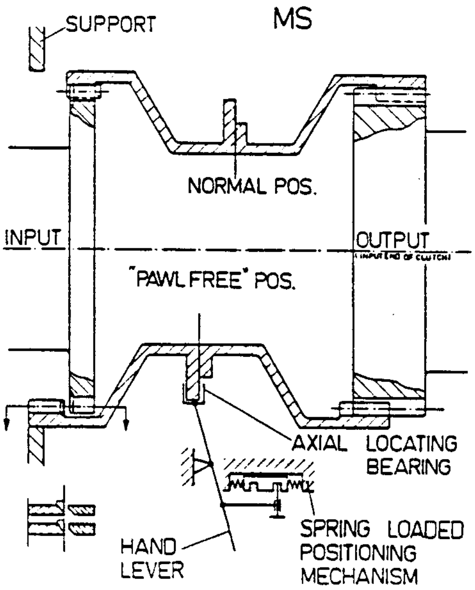

Fig. 14

The HS-clutch, which is already provided with lever and axial locating bearing, is additionally equipped with a hand lever and a spring loaded positioning mechanism, see Fig. 15.

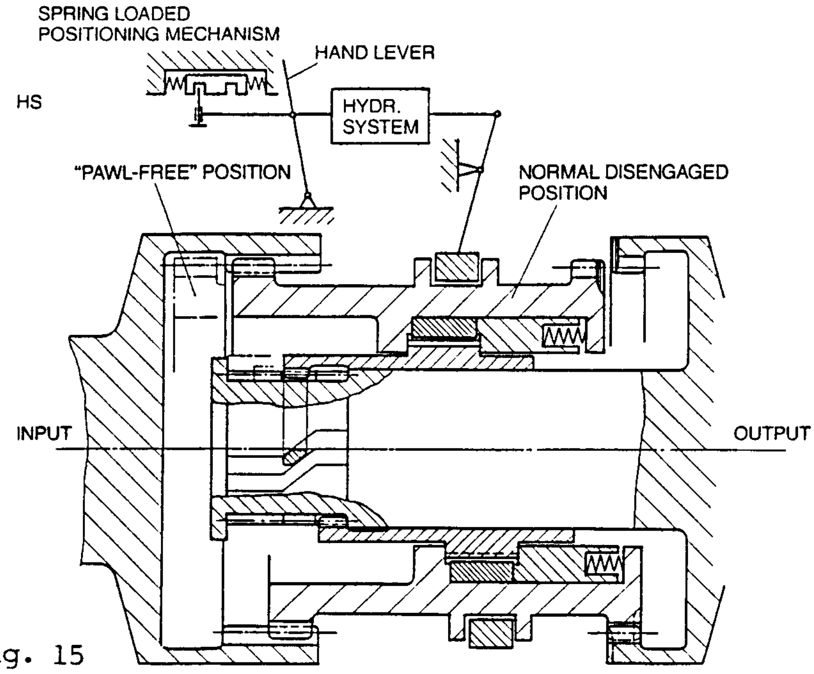

Fig. 15

For shifting the coupling sleeve into "pawl free" position the prime mover must be at standstill, but the output shaft system may be rotating or at standstill depending on the operational requirements of the propulsion system.

The disengaged tooth mesh can only be re-engaged when all shafts are at standstill. To ease engagement the tooth ends are champfered, but it may still be necessary to operate the turning gear of the gearbox to align and engage the coupling teeth.

3.3 Remote Operation

If remote control is required the axial shifting is effected by a hydraulic cylinder. The disengagement may take place while the shafts are rotating but with the prime mover at idle power.

For re-engagement the shaft of the prime mover has to be at stand-still, the output shaft system may rotate. A small brake has to be installed to stop the possible rotation of the coupling sleeve with the clutch being disengaged. To ensure positive re-engagement of the coupling teeth a simple synchronizing device is installed at the input side of the clutch.

3.4 Controls

The manually operated isolating device needs no controls, but limit switches are provided to signal the actual position of the clutch ("normal position" and "pawl free position") to the machinery control system.

To control the remotely operated isolating device solenoid valves for the hydraulic cylinder and the brake are provided. Limit- and pressure switches are installed to signal the actual position of the coupling sleeve and brake respectively.

The position signals are be used for indication and/or interlocks.

4. Locking Device for MS-Clutch

4.1 Basic Design

The clutch locking device, with which the MS-type clutch can be equipped, prevents the automatic disengagement of the clutch, when it has to transmit a negative torque.

During the disengagement movement the clutch hub 1, see Fig. 16 is

MS-R

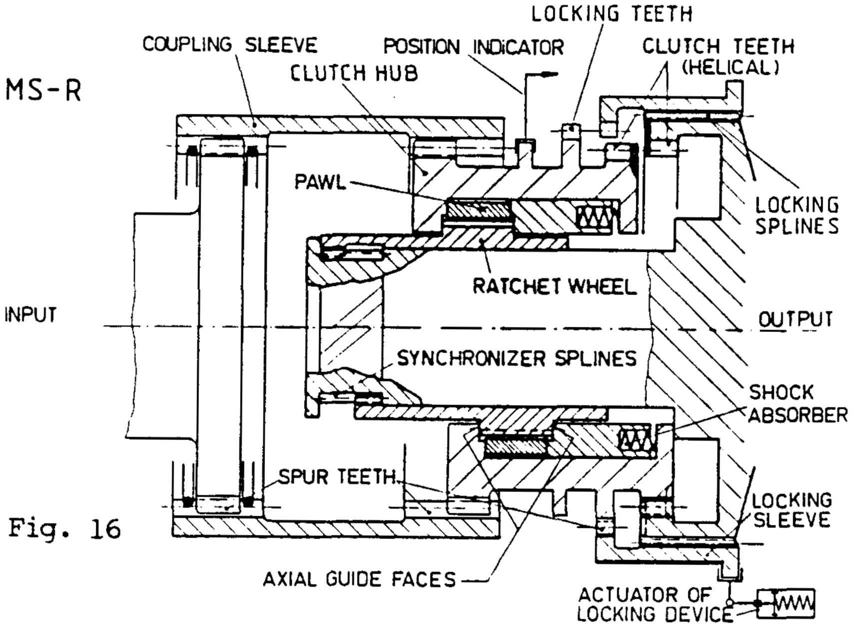

Fig. 16

performing a screw motion. By preventing it to performe this screw motion, an axial travel does not occur and hence, the clutch cannot disengage. This is achieved by a locking sleeve 2 having locking teeth 3 which, in locked position, are in mesh with the mating teeth 4 arranged on the clutch hub. The locking sleeve is located on the output shaft 5 of the clutch by locking splines 6 and can carry out an axial movement allowing the disengagement of the locking teeth. The locking sleeve is held in locked position by a spring 7 which acts via a lever and axial guide bearing on the locking sleeve. It can be brought in unlocked position by hydraulic force generated by lube oil acting on a spring loaded piston 8. The force is transmitted by the lever system to the locking sleeve. The locking teeth 3, 4 and the splines 6 may be made as spur or helical teeth, see Fig. 17/18.

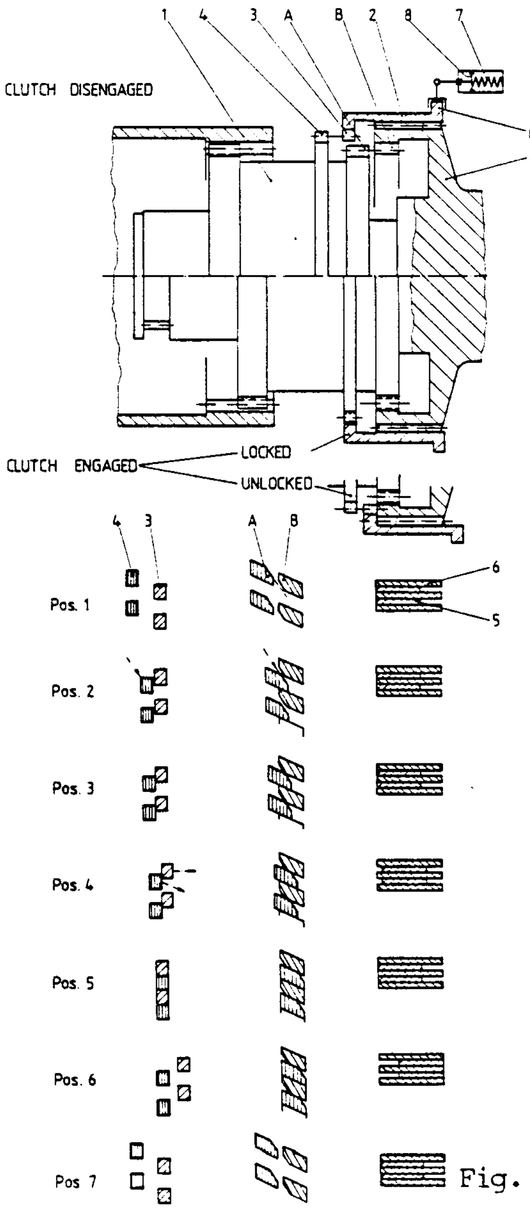

Fig. 17

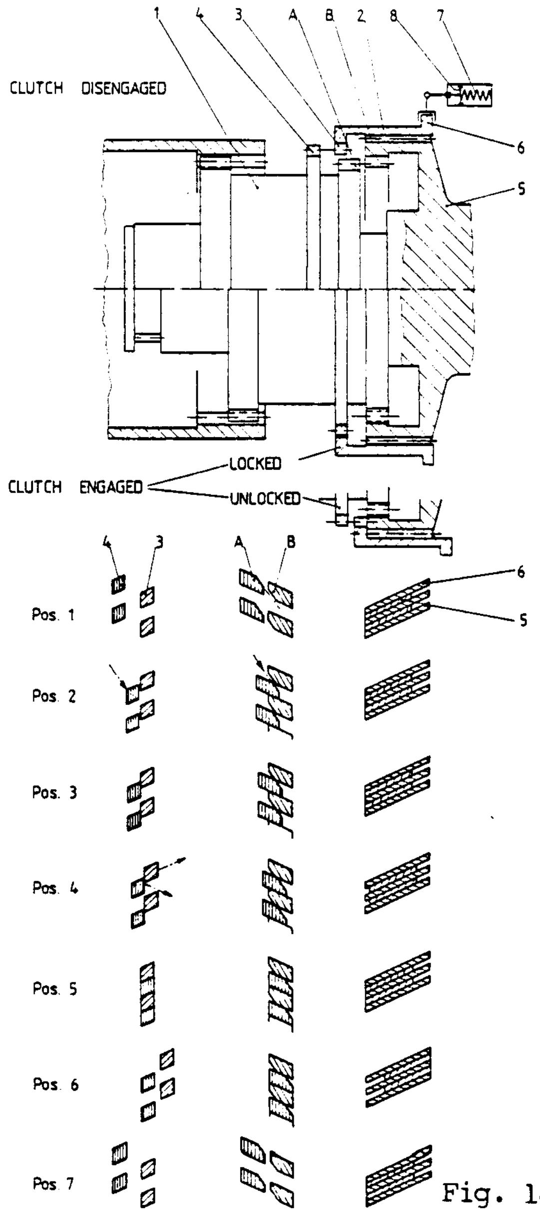

Fig. 18

Spur teeth are used to prevent the clutch to disengage under temporarily occuring negative torques. If operational conditions demand from the MS-clutch to transmit continously a negative torque helical teeth are employed for the locking teeth and the splines.

4.2 Function

4.2.1 Engagement and Locking of Clutch

State of components prior to engagement of clutch:
- output member rotates faster than input member
- clutch is disengaged
- signal on solenoid valve: "lock"
- axial position of clutch members according to Fig. 16 (shown above centre line)

Sequence of function:
- increase speed of input member
- when the input shaft overruns the output shaft, the clutch hub performs a screw motion, due to the accelerating torque of the prime mover, Position 1 in Fig. 17/18 shows the relative position of the clutch and locking teeth at synchronism
- after a certain axial travel the clutch teeth engage and are contacting on the flank, see Pos. 2
- the engaging screw motion now changes the pitch according to the helix angle of the clutch teeth
- after a further axial travel, the locking teeth abut in axial direction, see Pos. 3
- during the continuing travel, the spring loaded locking sleeve is pushed in axial direction by the face of the locking teeth of the synchronizing mechanism. The movement of the locking sleeve is purely axial or helical depending whether spur or helical teeth are used, see Pos. 4
- the timing of the locking teeth is such that just before the clutch hub abuts on the output member axially, the locking teeth obtain a relative position in which they can mesh. Due to the spring force, the locking sleeve snaps back to the original axial position. The locking teeth mesh and the clutch is thereby locked, see Pos. 5.
- the clutch hub is completely engaged, when it abuts on the output shaft

4.2.2 Unlocking and Disengagement of Clutch

State of components prior to disengagement:
- clutch engaged, transmitting power (positive torque)
- locking sleeve in locked position
- signal on seolenoid valve: "lock"
- axial position of clutch members according to Fig. 16 (shown below the centre line)

Sequence of function:
- prior to a selected disengagement of the clutch it is unlocked by giving the signal "unlock" to the solenoid valve
- pressurised oil is fed to the cylinder and by counteracting the spring force the locking sleeve is moved axially to the unlocked position, see Pos. 6
- reduce the speed of the prime mover
- as soon as the speed of the input shaft falls below the speed of the output shaft, the clutch disengages. At the end of the travel, the limit switch, detecting the clutch position, indicates "clutch disengaged", see Pos. 7
- subsequently to the signal "clutch disengaged", the command "lock" is given to the solenoid valve. The clutch is now ready to be re-engaged and locked.

4.3 Controls

Two signals, "unlock" prior to disengagement and "lock" after the disengagement is concluded, are required at the appropriate moment from the machinery control system to the solenoid valve controling the supply of oil to the hydraulic cylinder. Limit switches signal the actual position of the locking sleeve back to the machinery control system. These signals are be used for indication and/or interlocks.

5. Description of DS-Clutch

5.1 Introduction

Some applications require from the clutch, besides torque transmission and normal engaging and disengaging, that during certain operating conditions the output shaft of the clutch rotates at a lower speed than the input shaft. This requirement cannot be met neither by the MS nor HS clutch because both are functioning unidirectional with respect to synchronizing and engaging, they have to be designed for clockwise or anticlockwise rotation. This means that they remain disengaged and are acting like a free wheel drive, Fig. 2, as long as the output shaft rotates faster than the input shaft. The free wheeling condition can also be expressed by the following equation:

$n_{output} - n_{input} = \Delta n$ = positive value (n = rotating speed)

This equation is also valid when the shafts are rotating contrary to their normal direction of rotation for which the clutch has been designed. The value of rotational speed has to be set positive in case the rotation is in normal direction or negative if the shafts are rotating contrary to the normal direction of rotating.

Should the difference of rotational speed become negative the MS or HS clutch would synchronize and engage.

5.2 Basic Design and Function

To cope with the requirement that the output shaft may rotate at a lower speed than the input shaft 2 simple MS-clutches are arranged in

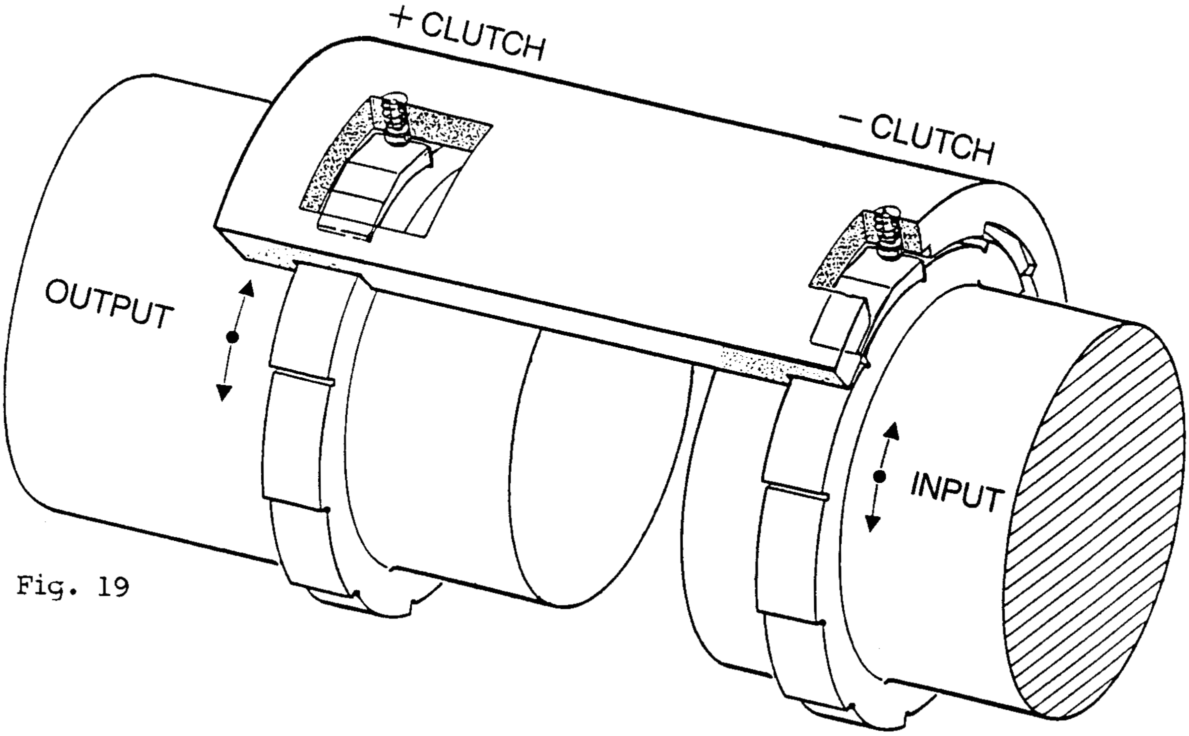

Fig. 19

series forming the DS clutch, see Fig. 19 in which, for simplicity, the clutches are represented as free-wheels. The

+ free wheel (or clutch) is designed for the normal direction of rotation, the
- free wheel (or clutch) is inverted and takes care of the reversed direction of rotation.

When the output shaft rotates faster than the input shaft (Δn = positive) the +free wheel (or clutch) is free-wheeling whereas the -free wheel (or clutch) is engaged. If the input shaft rotates faster than the output shaft (Δn = negative) the +free wheel (or clutch) is engaged and the -free wheel (or clutch) is free wheeling. This course of events is shown graphically in Fig. 20, in which n_1 and n_2 repre-

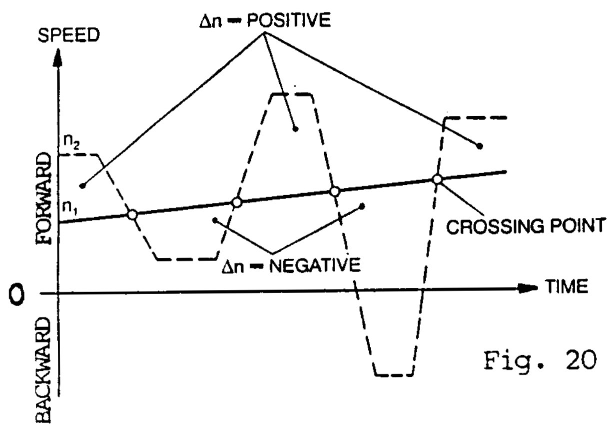

Fig. 20

sent the speed of the input and output shaft respectively. At the crossing points the + and - clutch hubs engage or disengage depending wether the differential speed becomes negative or positive.

It is evident that with the clutch arrangement as shown symbolically in Fig. 19 a torque transmission from the input prime mover to the output shaft driven equipment is not possible because the -free wheel (or clutch) disengages. By providing both free-wheels (or clutches) with a locking device, as shown in Fig. 21, torque can be transmitted in either direction, when the free wheels are locked.

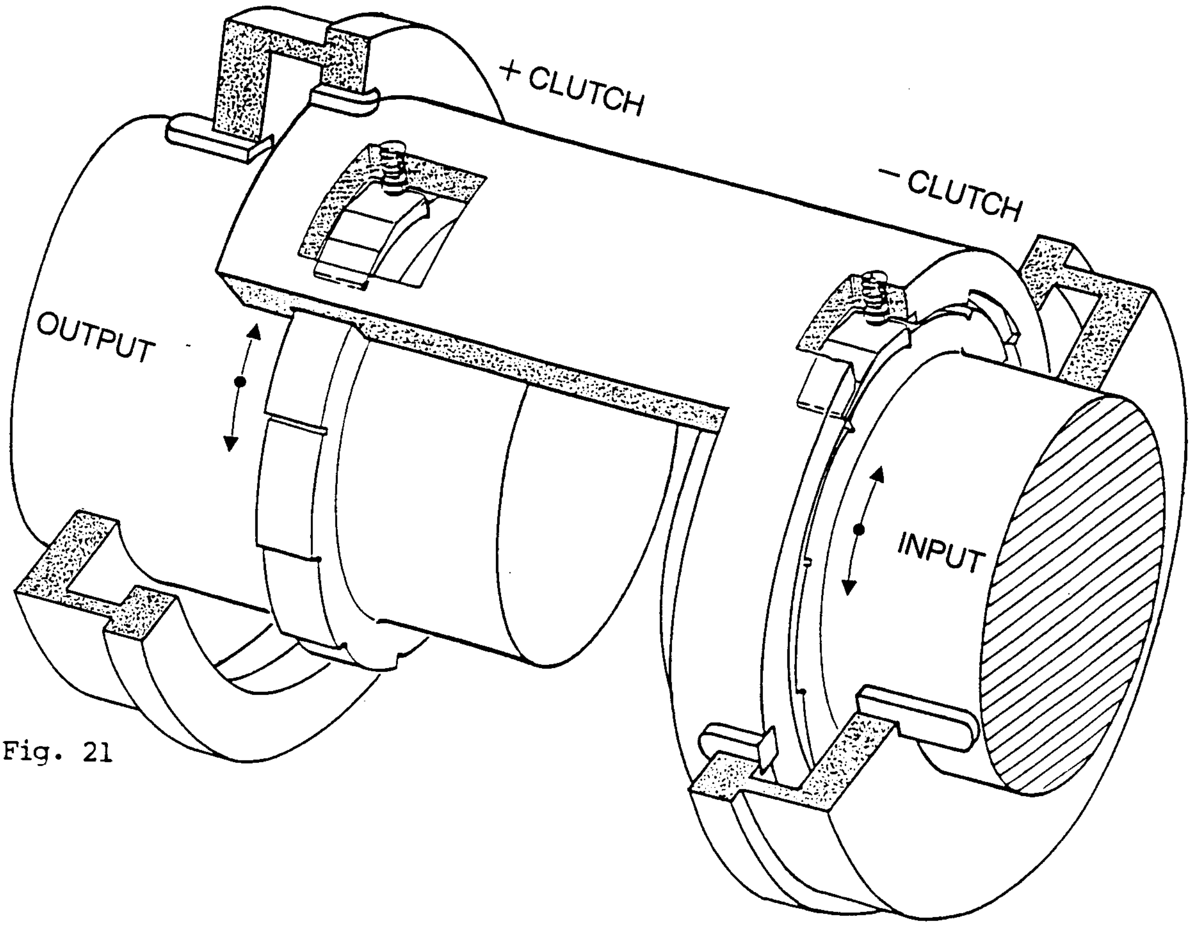

Fig. 21

The proper DS-clutch may therefore be composed of:

2 MS-clutches with locking devices, Fig. 22

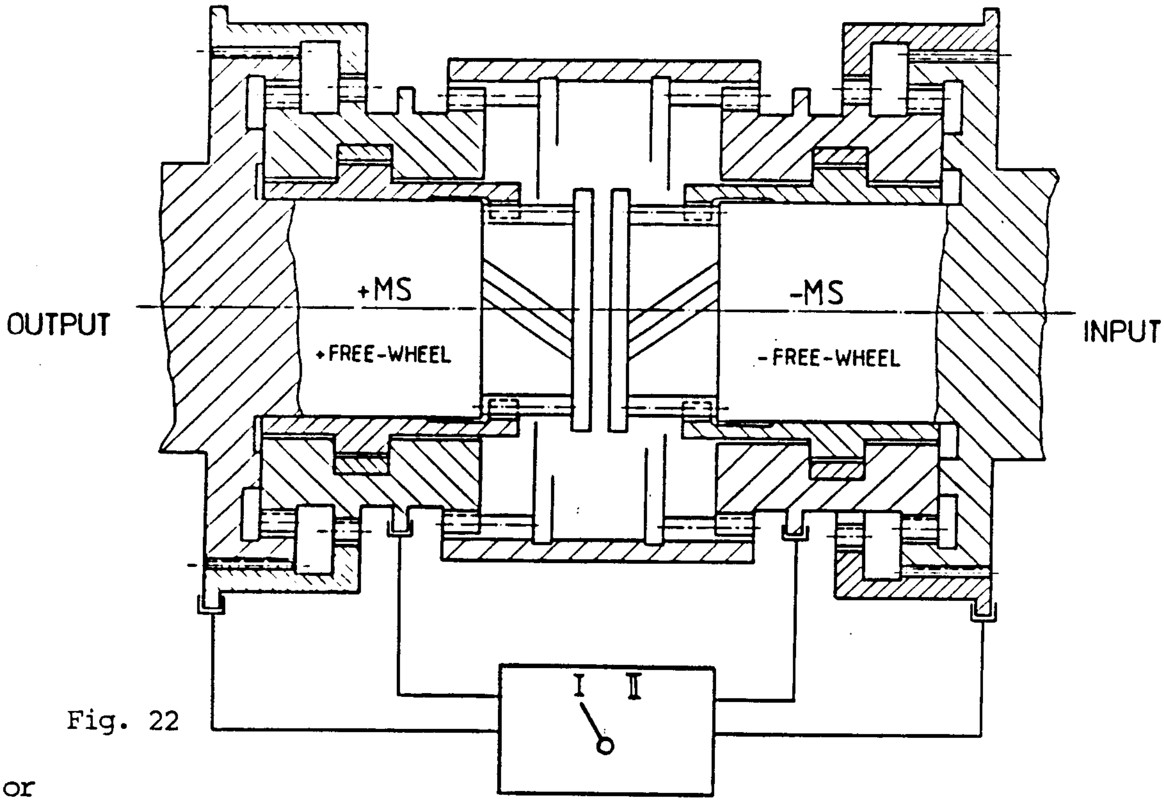

Fig. 22

or

1 HS-clutch (-free-wheel) and 1 MS-clutch with locking device (+free-wheel), Fig. 23

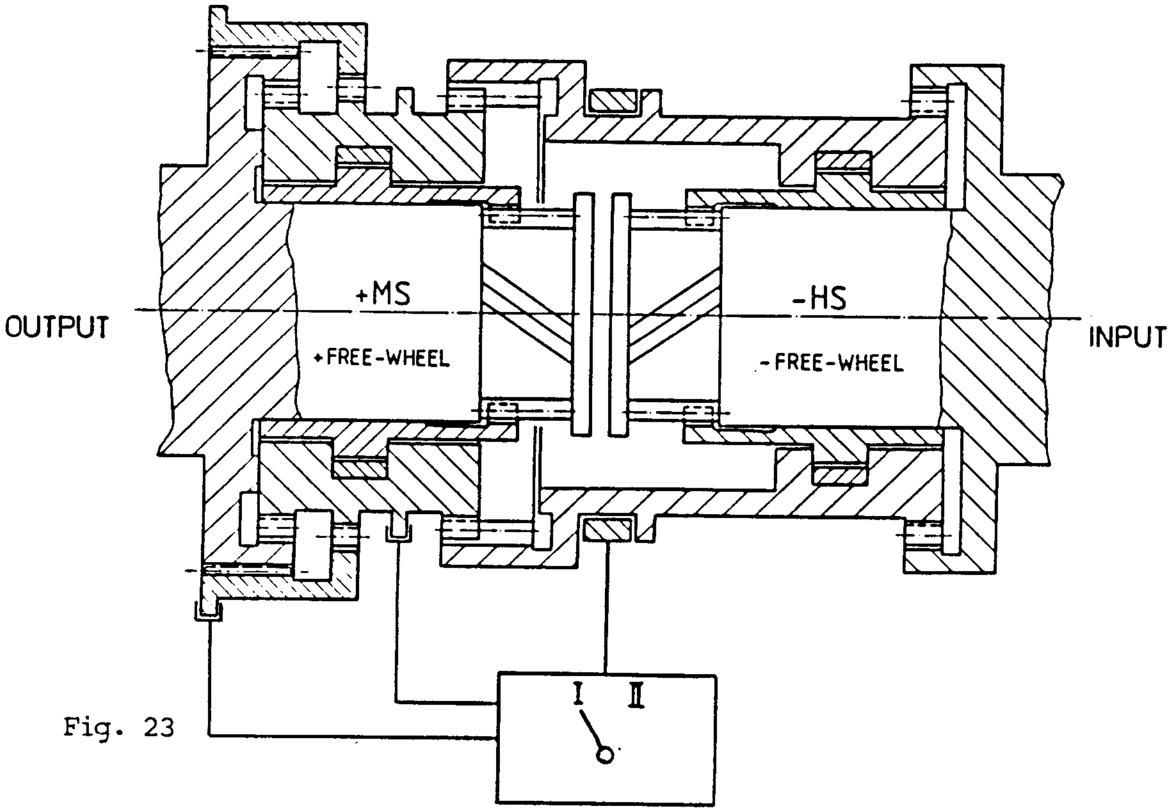

Fig. 23

If the prime mover is operating unidirectional the +MS-clutch is equipped with a spur locking device. The torque developed by the prime mover is for the -clutch (inverted clutch) a negative torque, therefor the HS-clutch is an obvious choice but a MS-clutch with a helical locking device is also suitable to be used as -free-wheel.

Is the prime mover operating bidirectional than the +MS-clutch is provided with a helical locking device.

When fully engaged the DS-clutch operates like an ordinary toothed coupling allowing shaft misalignement and axial shaft expansion.

5.3 Controls

The DS-clutch has an integrated hydro-mechanical control system which prepares the double clutch to function according to the operating mode selected by the main machinery control system. The DS-clutch distinguishes between the two following operating modes:

I Torque transmission

II Free-wheeling

The electrical signals, selecting mode I or II, can be transmitted from the machinery control system to the clutch at any time regardless of the momentary state of the clutch. The signals do not trigger-off any immediate movements of the clutch hubs, they simply prepare the integrated clutch control system to allow the DS-clutch to perform according to the selected operating mode when the appropriate conditions (speed, torque) prevail at the DS-clutch.

This is illustrated in Fig. 24, which shows the change-over from the

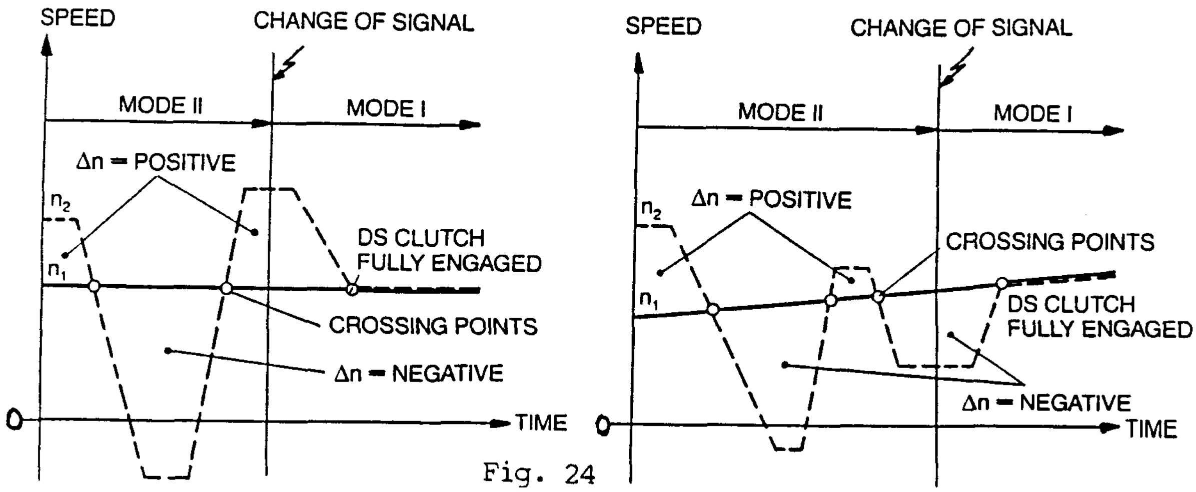

Fig. 24

operating mode II (free wheeling) to mode I (torque transmission). During free-wheeling one of the clutch hubs is always engaged. When the signal "mode I" is given, the momentarily engaged clutch hub is locked, for the other the locking device is activated. When input and output shafts achieve synchronism the disengaged clutch hub engages and locks (crossing point). It is insignificant whether synchronism is achieved out of a positive or negative differential speed condition.

Prior to a change-over from mode I (torque transmission) to mode II the torque is reduced, subsequently the signal for the change-over is given to the DS-clutch.

If the DS-clutch is composed of two MS-clutch hubs, the signal unlocks the clutch hubs and the DS-clutch is prepared for free-wheeling as soon as one of the shaft speed increases or decreases.

In case the DS-clutch is formed by 1 MS- and 1 HS-clutch hub, the signal unlocks the MS-clutch hub. To achieve free-wheeling sequence it is necessary to first reduce or increase the speed of input or output shaft respectively. Subsequently any speed changes are allowable.

The DS-clutch is equipped with limit switches which signal the actual position of clutch hubs and locking sleeves back to the machinery control system. The signals are used for indication and/or interlocks.

6. Conclusions

The main characteristic features of the MS, HS and DS clutches are:

- Torque transmission is the same as in standard toothed couplings, combining torsional rigidity with axial and angular flexibility.
- Suitable for transmitting practically any torque at any speed for which toothed couplings can be applied.
- The synchronizing mechanism is of relatively light but still robust construction. Therefore high angular accelerations at engagement are permissible.

- Due to high manufacturing and balancing standards the generation of structure borne noise is negligible. The clutch does not contribute to the air borne noise level of the coupled machines.

- The clutches, functioning purely mechanically, are highly reliable and free of wear.

With the following table the appropriate clutch type can be selected for given operating requirements.

<table>
<tr><th>Rotation</th><th>Operational Requirements</th><th colspan="2">Recommended clutch type</th></tr>
<tr><td rowspan="3">Unidirectional</td><td>no torque reversals</td><td colspan="2">MS</td></tr>
<tr><td>short time torque reversals</td><td colspan="2">MS-R(S)</td></tr>
<tr><td>transmission of positive and/or negative torque</td><td>MS-R(H)</td><td>HS</td></tr>
<tr><td rowspan="2">Bidirectional</td><td>freewheeling and transmission of positive torque</td><td colspan="2">DS
MS-R(S)+MS-R(H)
MS-R(S)+HS</td></tr>
<tr><td>transmission of positive and/or negative torque</td><td colspan="2">DS
MS-R(H)+MS-R(H)
MS-R(H) + HS</td></tr>
</table>

Legend: positive torque = torque transmission from input shaft to output shaft
negative torque = torque transmission from output shaft to input shaft
MS-R(S) = MS clutch with spur locking device
MS-R(H) = MS clutch with helical locking device

MAAG offers with the MS, HS and DS clutches including the optional devices a comprehensive product line which makes it possible to comply with any operational requirements of modern marine propulsion systems, of today and in future.