

Design and Application for Synchronous Clutch Couplings: MS and HS types

ABSTRACT

The synchronous clutch coupling has been designed to be used in high power and speed machinery to couple and decouple shaft systems while they are operation. The clutch is a combination of a free-wheel and a toothed coupling taking care of synchronizing and torque transmission respectively. The overall efficiency of Cogeneration- and Combined Heating Power-plants can be considerably increased by using the clutch to decouple a prime mover from an operating machinery train, wherein the selected operating mode of the prime mover would produce losses if remained coupled with the train.



INTRODUCTION

Several different types of clutches are known and can be successfully applied to decouple shaft systems, they are shown in Fig. 1. Each one has its distinct advantages and disadvantages. For high power/speed applications, which prevail in turbo machinery plants, the "form-fit" type clutches only can cope with the operating conditions.

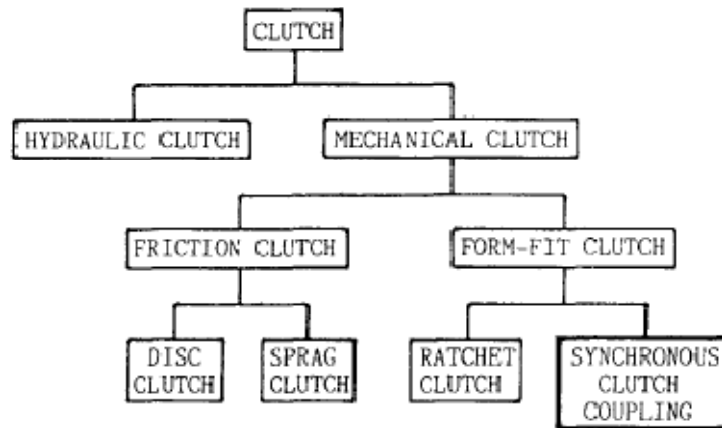


FIG. 1 CLUTCH TYPES

Toothed couplings are form-fit couplings. They are widely used in turbo machinery installations, because of their ability to transmit high torque high speed and at the same time to accept misalignment 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 deceleration turbo machinery can achieve it is indispensable that the clutch-coupling functions are fully automatic. Disengaging a toothed coupling presents no specific problem, however re-engaging the coupling is more difficult because 2 conditions must be fulfilled by the shafts to be coupled:

- 1) **Equal speed (synchronization)**
- 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. 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 bicycle.

Placed between two shafts, acting as the clutch, the free-wheel allows one shaft (output side) to rotate free in one direction with the other shaft (input side) at standstill. By acceleration 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 angular position of input and output shaft at synchronism would be identical at each engagement (condition 2). A free-wheel having 6 pawls and 11 ratchet teeth has 66 possible engagement positions, since one pawl only engages with a ratchet tooth at each engagement, it is suitable to align a toothed coupling having 66 teeth. The free-wheel device is therefore 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-wheels synchronizing mechanism form the Synchronous Clutch Coupling.

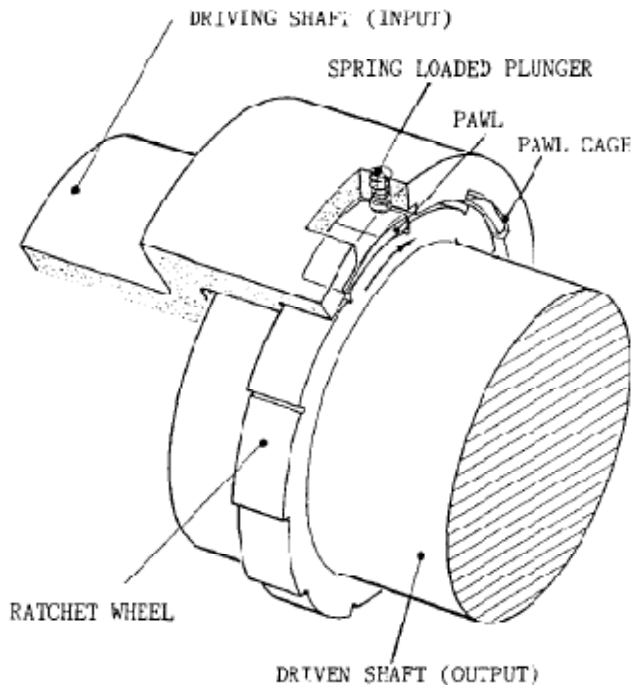


FIG. 2 FREE WHEEL

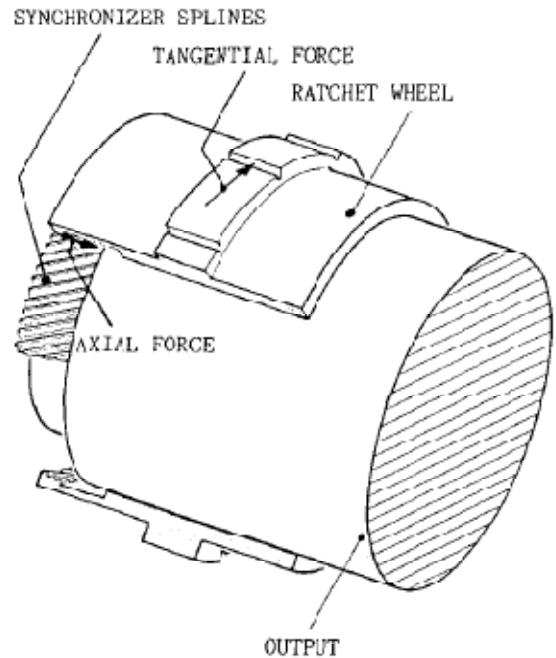


FIG. 3 RATCHET WHEEL

Design and Function of the Synchronous Clutch Coupling

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 freewheel, see FIG. 2, is modified by separation of the ratchet teeth from the output shaft. A ratchet wheel is created which is supported on the output shaft and connected to it by synchronizer splines (helical splines), see FIG. 3. When a pawl is acting on the ratchet wheel, it performs a screw motion, relative to the output shaft, which is governed by the synchronizer splines. The clutch is formed by placing the engaging clutch hub around the ratchet-wheel, see FIG. 4. It is assumed that the output shaft together with the ratchet wheel is rotation and that the input shaft with the pawls is at standstill. By acceleration the input shaft it will eventually overrun the output shaft, and a pawl will engage with a ratchet tooth. Part of the accelerating torque developed by the input shaft (driving machine) 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. The clutch hub in which the pawls are located is guided axially by the ratchet wheel and has therefore to follow the movement. To allow the axial movement, the clutch hub is connected by straight splines to the input shaft. The external and internal clutch teeth to be engaged are arranged on the clutch hub and on the output shaft respectively.

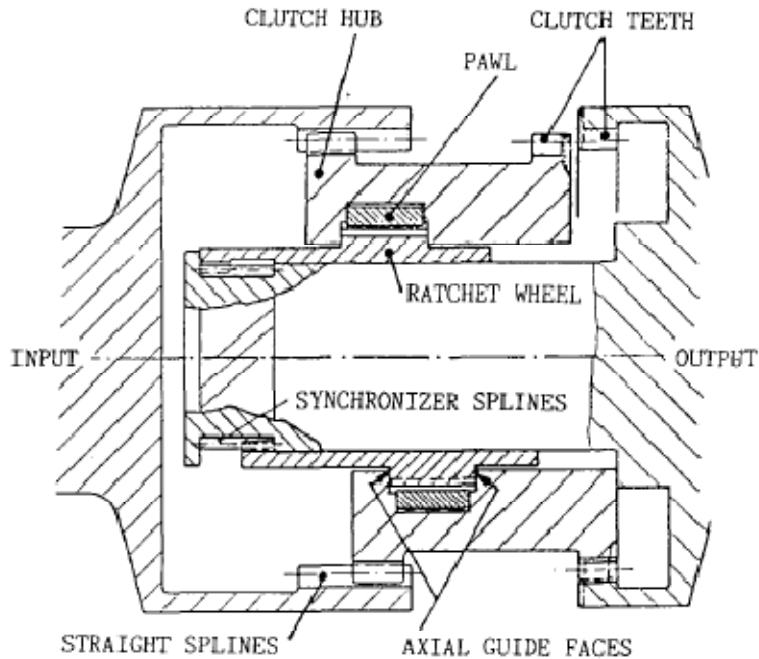


FIG. 4 BASIC CLUTCH

These teeth are brought into engagement by the screw movement which the clutch hub performs relative to the output shaft. The teeth are transferred giving ample clearance for engagement. The clutch teeth are making contact because its helix angle is smaller than the helix hub. The synchronizing phase is concluded when the flanks of the clutch teeth make contact, as shown in FIG. 5.

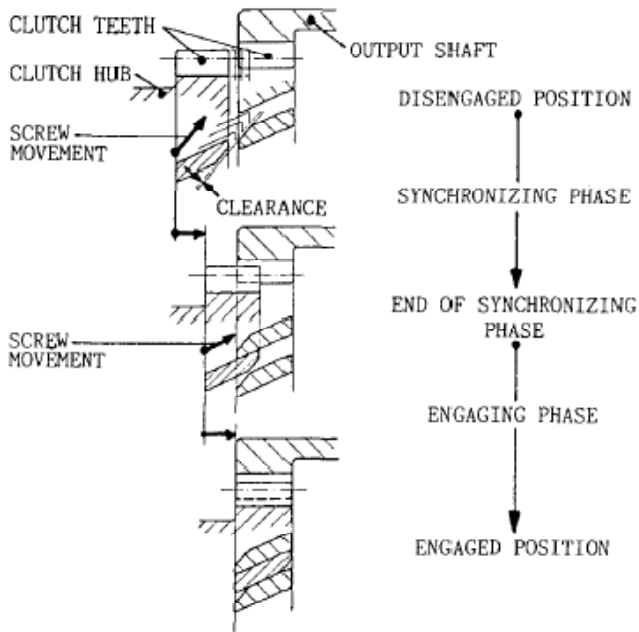


FIG. 5 SYNCHRONIZING AND ENGAGING PHASES
MS-CLUTCH

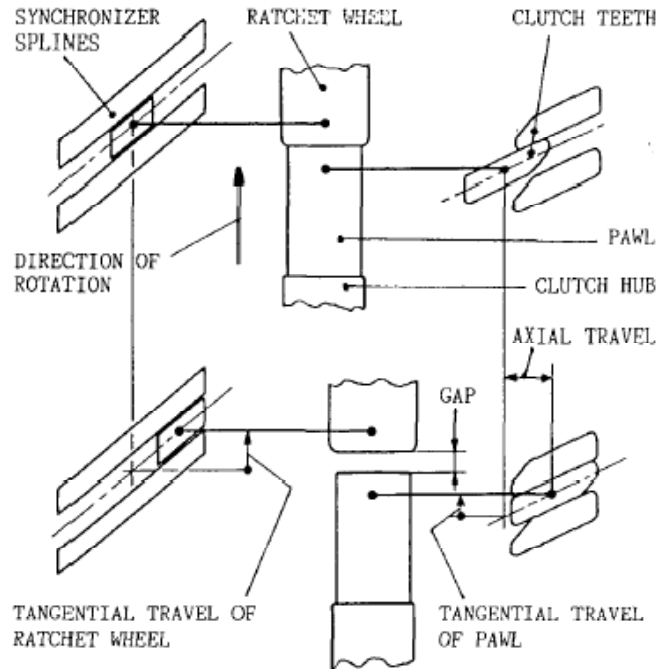


FIG. 6 UNLOADING OF THE PAWL

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 with the output shaft, thus concluding the engagement phase. During this phase the pawl having been in contact is being unloaded by a relative tangential movement between pawl and ratchet tooth which results from two different screw movements performed by the clutch hub and the ratchet wheel. The ratchet wheel is guided in the synchronizer splines having a large helix angle, therefore the travel is over a large tangential distance, whereas the pawl is guided by the clutch teeth having a smaller helix angle, consequently the pawl travels a shorter tangential travel, resulting in a gap between pawl and ratchet tooth, see FIG. 6 (plan view).

With the clutch fully engaged the rated torque can be immediately transmitted. The only elements loaded by the torque are the straight splines and 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. The engagement sequence is now concluded, 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 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, 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 axial force just before the synchronizing phase is concluded, see FIG. 7. During the synchronizing phase no external force is allowed to act on the pawl carrier.

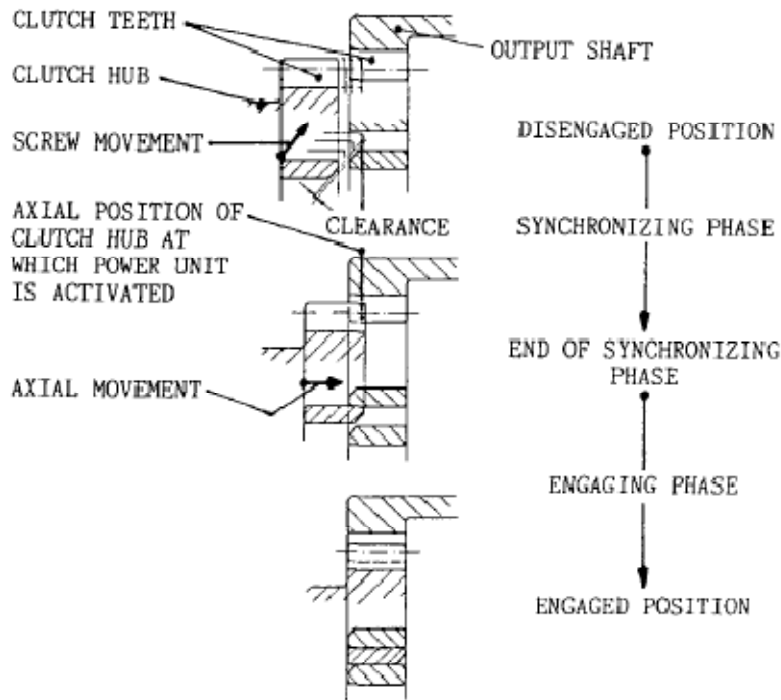


FIG. 7 SYNCHRONIZING AND ENGAGING PHASES OF HS-CLUTCH

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

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

- **Clutch having helical clutch teeth—MS-clutch**
- **Clutch having straight clutch teeth—HS-clutch**

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 described in the following paragraphs, have to be incorporated.

Pawl, Ratchet Wheel

When disengaged, clutch the output shaft and the ratchet wheel may rotate at full speed whereas the input shaft with the pawls is at standstill. The contact faces of these components are lubricated by injected lube oil. A hydrodynamic oil film between pawls and ratchet teeth preventing metallic contact is generated due to the relative speed and the suitable shape of these components, see FIG. 8.

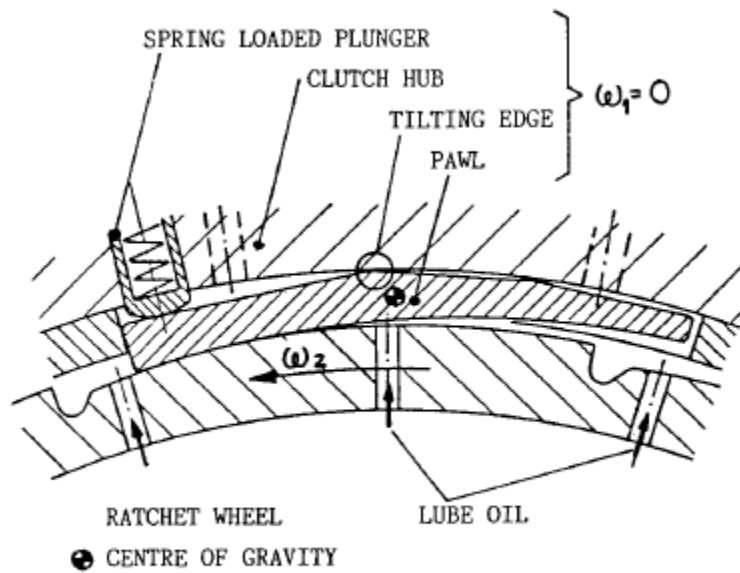


FIG. 8 PAWL LOCATION AND LUBRICATION

The pawls, located with ample clearance in cages formed by two rings, are completely free to move. A tilting edge on the outer contour and the tail-heaviness of the pawl insure that the nose is lightly pressed on to the ratchet wheel when the input shaft is accelerated for an engagement. 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. The pawl nearest to a ratchet tooth contacts first, initiating the synchronizing phase.

With a 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.

Shock Absorber

When a pawl hits a ratchet wheel tooth, 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.

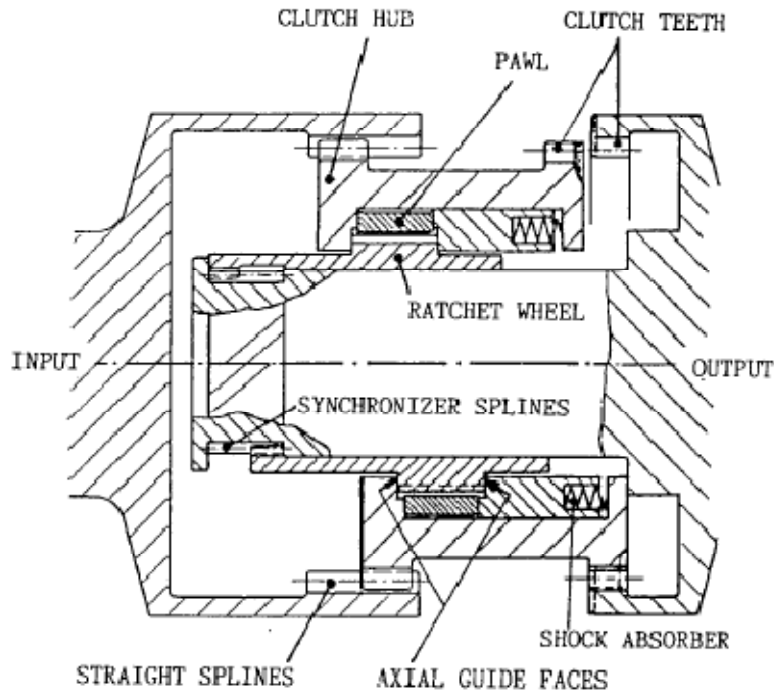


FIG. 9 CLUTCH WITH SHOCK ABSORBER

The effect is that the pawl load is then mainly determined by a spring- and not by a mass-force. The pawl carrier 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 engagement of the clutch at high relative angular accelerations. Typical accelerations of turbo machinery are:

- 1000 RPM/sec (small power)
- 500 RPM/sec e.g. 20 MW at 3600 RPM (medium power)
- 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, then the relative acceleration the clutch has to sustain is equal to the sum of acceleration of the input shaft and the deceleration of the output shaft.

Toothed Coupling

The engaging helical clutch teeth of the MS-clutch are tightening the pawl-carrier to the output shaft when the clutch is transmitting torque. The axial force generated in the clutch teeth is taken up by the abutment; therefore 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 misalignment. To have a fully flexible coupling a second straight tooth mesh is added on the input side, FIG. 10 is showing this arrangement. The coupling sleeve, axially located at the input side mesh, is connecting the two shafts and allows for any possible misalignment.

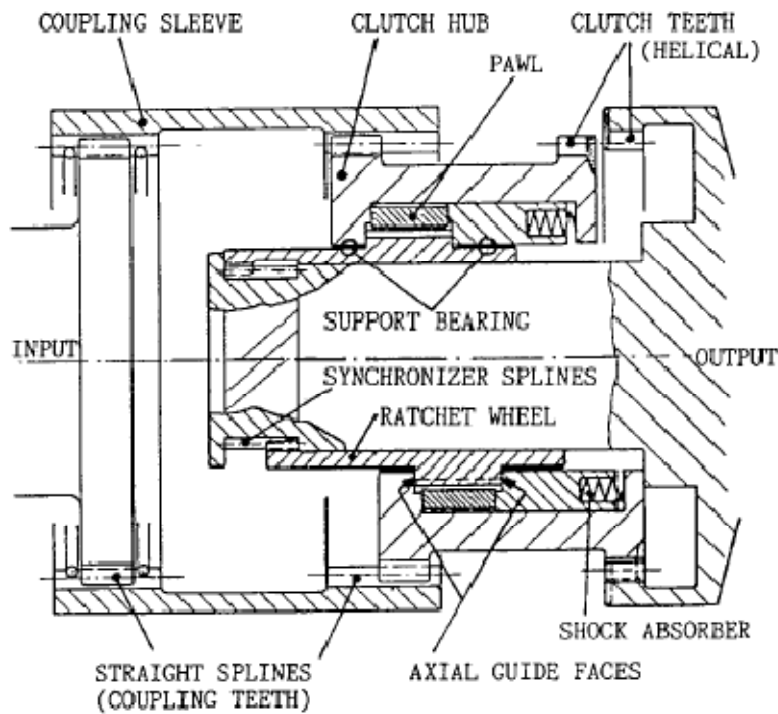


FIG. 10 MS-CLUTCH COUPLING

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.

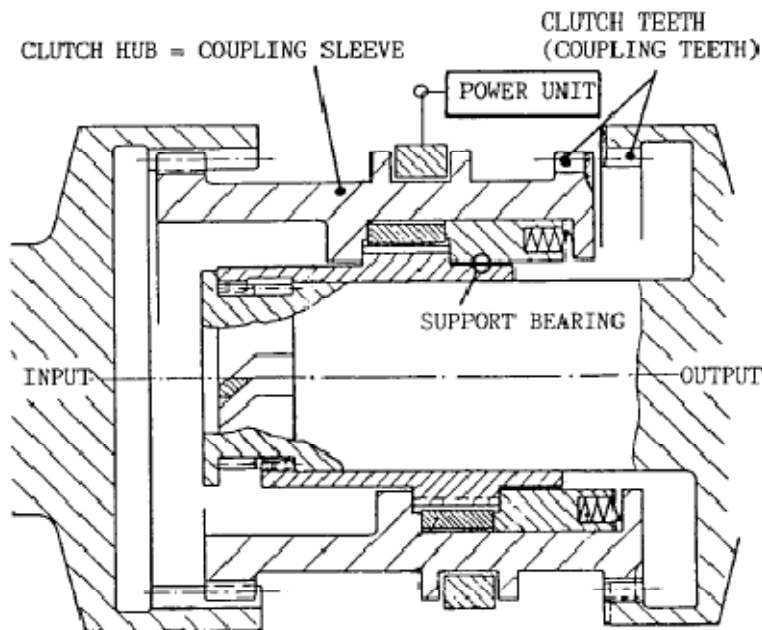


FIG. 11 HS-CLUTCH COUPLING

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 come 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 in the associate axial guide bearing arranged around the ratchet wheel. A small drag torque is transmitted from the output shaft to the input shaft. Since the drag torque is for the clutch 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.

Lubrication

Lube oil is injected into the clutch hub to lubricate all the components, such as support bearing, axial guide bearing, ratchet wheel and pawls, which see relative movement when the clutch is disengaged. 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 operation with misaligned shafts.

APPLICATIONS

Due to the compactness of the synchronizing mechanism the MS and HS clutch couplings have a wide field of applications. They are successfully operating in:

- **Peaking power plants** (FIG. 12, photograph 12)
- **Combined cycle units and Cogeneration** (FIG. 14, photograph 15)

- **Air storage power plants** (FIG. 16, Photograph 17)
- **Expander drives in petro-chemical plants** (FIG. 18, photograph 19)
- **Combined ship propulsion plant** (CODOG, COGOG etc.)
- **Turning gears**

For most applications the MS-clutch is suitable, if however certain operation condition of a plant demand a continuous transmission of a negative torque than the HS-clutch is applied.

The basic design of the clutch coupling allows many variations which helps adjusting the design to particular space and operating requirements. The clutches can be equipped with additional features like:

- a) locking mechanism for the MS-clutch, preventing the disengagement during transient negative torques
- b) limited end float couplings, locating axially rotors of electrical machinery
- c) quill shaft arrangement applied in connection with a gearbox
- d) electrical insulation in connection with electrical machinery
- e) hydraulic coupling for HS-clutch, permitting the start up of a one shaft gas turbine using the rotating alternator as starting motor (peaking power plant)
- f) manually operated isolating device, allowing to operate the input side while the output shaft is at standstill (e.g. washing of gas turbine)

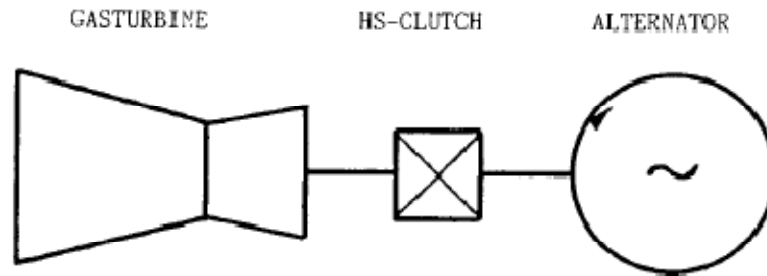


FIG. 12 PEAKING POWER STATION



Photograph 13, Clutch of Fig. 12

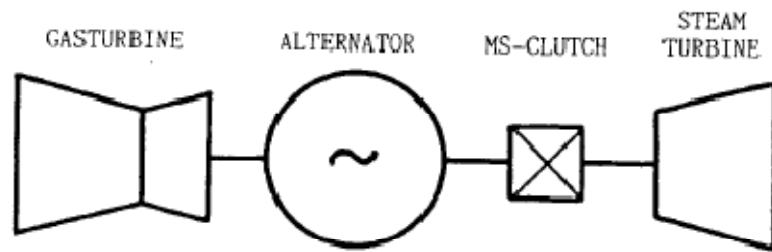
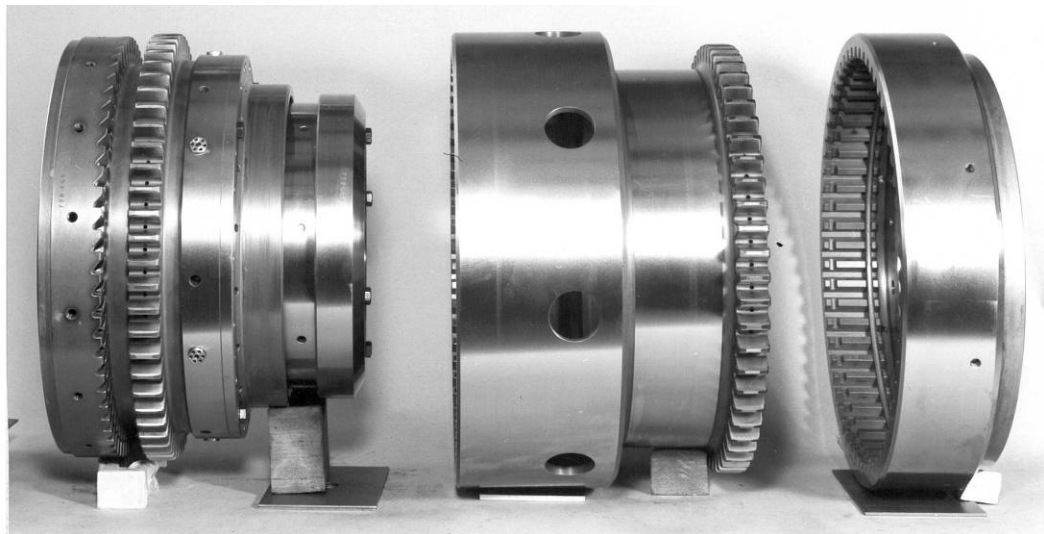


FIG. 14 COMBINED CYCLE UNIT



Photograph 15, Clutch of Fig. 14

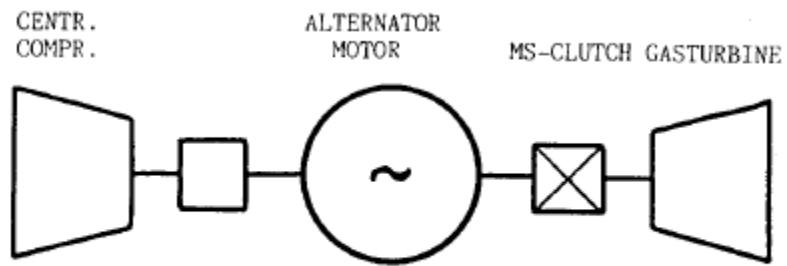


FIG. 16 AIR STORAGE POWER PLANT



Photograph 17, Clutch of Fig. 16

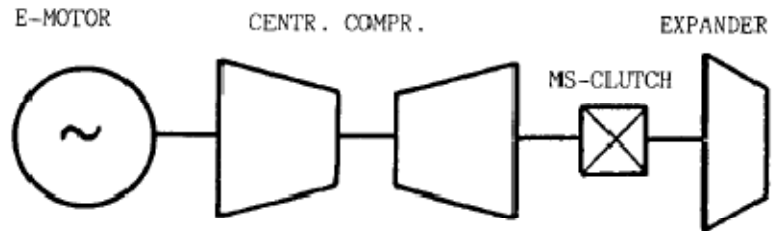
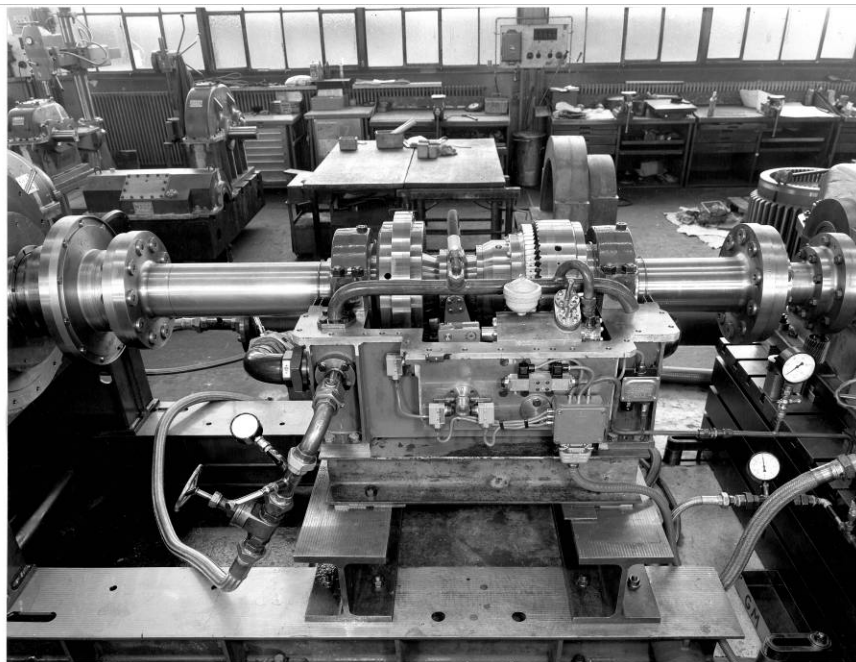


FIG. 18 EXPANDER DRIVE

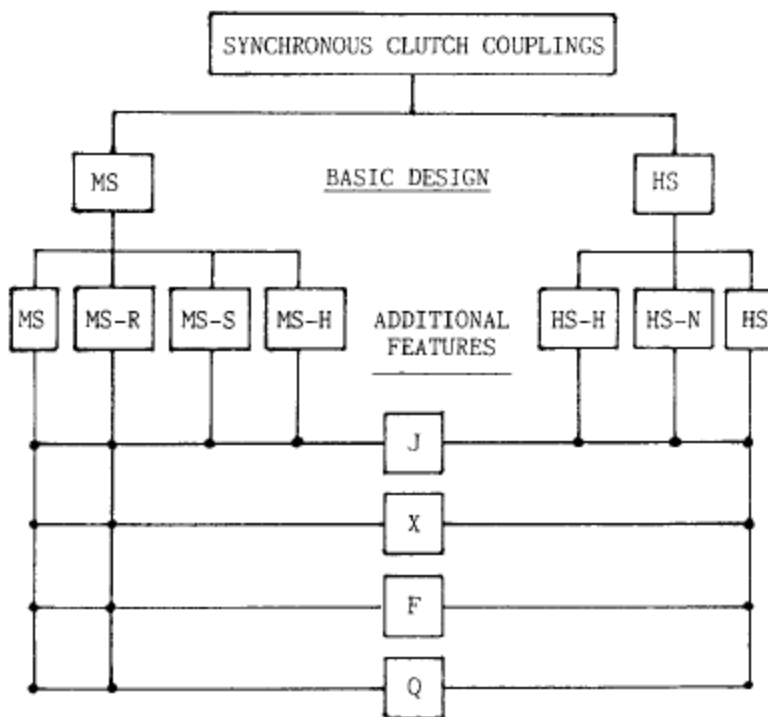


Photograph 19, Clutch of Fig. 18

The expenditure of controls for a clutch is minimal and depends largely on the operating requirements. The MS-clutch basically needs no control requirements. The MS-clutch basically needs no control at all. It can be equipped with limit switches to indicate its position. The locking device, if used, needs an external signal for unlocking the clutch. The HS-clutch needs two external signals, one to prepare the hydro-mechanic power unit for engagement, the other to disengage the clutch.

The clutch coupling is an overrunning clutch, therefore the speed control of the driving machine 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. It must not be attempted to achieve equal speed of the two shaft systems, otherwise the engagement will never take place.

The combination possibilities are shown in FIG. 20.



Legend

- | | |
|----------------------------|---------------------------------|
| R: locking mechanism | J: electrical insulation |
| S: rigid when engaged | X: limited end float |
| H: with hydraulic coupling | F: isolating device (pawl free) |
| N: engagement at low speed | Q: quill shaft arrangement |

FIG. 20 FEATURE DIAGRAM FOR TYPE HS AND MS SYNCHRONOUS CLUTCH COUPLINGS

Both, the MS- and HS-clutch, allow for continuous operation at relatively small speed difference. For example in a peaking power unit is the alternator operation as synchronous condenser at synchronous speed, say 3600 rpm, and the gas turbine may be idling with 3200 rpm, the synchronizing components of the clutch will then see a speed differential of 400 rpm. Due to the correct shape of the synchronizing components and the positive lubrication no wear will occur in the clutch.

The clutch coupling is also suitable to be installed into existing plants as re-fits; because it is basically a toothed coupling the behavior of the clutch coupling will be comparable to the one of the replaced coupling.



CONCLUSIONS

The MS- and HS-clutch couplings are elements which can be successfully applied in high power / high speed industrial machinery trains, mainly because of:

- ✓ **compact design**
- ✓ **minimal number of components**
- ✓ **positive synchronizing action**
- ✓ **purely mechanically operated**
- ✓ **sturdy and simple design**
- ✓ **allowing high acceleration**
- ✓ **no losses when engaged**
- ✓ **full flexibility in radial and axial direction**
- ✓ **low residual unbalance**

In addition to the technical arguments it is the high return of investment this product offers with makes it so attractive.



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