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# Application of Taguchi methods and ANOVA in optimization of process parameters for Hybrid Power Transmission in Fluid Coupling

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***ABSTRACT:*** *The objective of the present work is to investigate experimentally the effect of process parameters such as viscosity of Fluid, Fluid filled and Input Power. Taguchi methods are widely used for design of experiments and analysis of experimental data for optimization of processing parameters. The research contributions are classified into methodology for investigation and analysis of input processing conditions and response variables. This paper focuses on the optimization of process parameters for power transmission in Fluid coupling using the Taguchi technique to obtain maximum output power. A number of experiments were conducted using the L9 orthogonal array on a Hybrid Fluid Coupling. The experiments were performed with different viscosity of Fluids at various filling capacities. Analysis of variance (ANOVA) was employed to determine the most significant control factors affecting the output power. The viscosity of Fluids, Fluid filled and Input Power were selected as control factors. After the nine experimental trials, it was found that the Input Power was the most significant factor for obtaining maximum power. The results of the confirmation experiments showed that the Taguchi method was notably successful in the optimization of Fluid Coupling parameters for better output power. Commercial software package Qualitek-4 is used for performing the analysis.*

***KEY WORDS: Fluid coupling, Taguchi method, Analysis of Variance and power transmission***

## 1. INTRODUCTION:

Fluid couplings are used in engineering applications due to their unique features in flexible transmission of shaft torque between a pair of driving and driven shafts. Fluid coupling operates on the hydrokinetic principle without mechanical contact between driving and driven shafts. A fluid coupling principally consists of a pump impeller, turbine runner and working fluid enclosed in an oil tight chamber or casing. The driving wheel works as a pump impeller, imparting angular momentum to the working fluid, while the driven wheel works as a turbine runner, receiving the angular momentum from the fluid. Therefore, a flexible transfer of shaft torque is realized from the driving pump impeller to the driven turbine runner through the working fluid without mechanical contact. The chamber is filled with fluid, and a circulation is established in the coupling circuit which leads to exchange of angular momentum between the impeller and runner through fluid. The impellor of the fluid coupling is directly connected to the prime mover like motor or I.C.Engine by mechanical coupling. The impellor is power input component of the fluid coupling. The runner is directly connected to the machine by mechanical means like Belt drive, gear drive or a mechanical coupling. The runner is power output component of the fluid coupling.

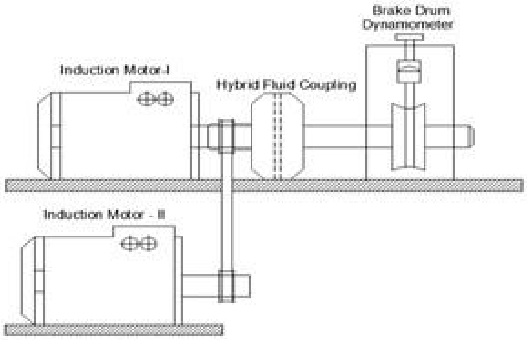
Working fluid of the fluid coupling is the important parameter of the system. The working fluid in the fluid coupling is filled between impellor and runner which gets energies by rotation of impellor and converts impellors energy in the kinetic energy of the fluid, this kinetic energy of the fluid get absorbed while striking on runner. And by this energy the runner rotates and power transmitted to the machine.

The present investigation is aimed to analyze various factors, which affect the performance of fluid coupling. The parameters under investigation are fluid with varying viscosities, Filled Capacity of fluid in fluid coupling and input power.

Taguchi's Parameter design suggests an efficient approach for optimization of various parameters with regard to performance, quality and cost. Taguchi recommends the use of S/N (Signal to Noise) ratio for the determination of the quality characteristics implemented in engineering design problems. The addition to S/N ratio, a statistical analysis of variance (ANOVA) can be employed to indicate the impact of process parameters on output power. In this paper Taguchi's DOE approach is used to analyze the effect of power transmission process parameters such as viscosity of Fluid, Fluid filled and Input Power for maximum power transmission through Fluid Coupling and to obtain an optimal setting of the parameters that results in optimizing the output power.

## 2. MODEL DESCRIPTION:

In a typical Hybrid Fluid coupling used, the pump impellers (2 Nos.) and turbine runner are geometrically identical and mounted back to back with little separation between the leading and trailing edges. A first impeller is connected with the external input shaft and a second impeller is connected with internal input shaft. The runner is connected with the output shaft which is coupled with brake dynamometer. A commonly used impeller/runner having 24 radial vanes with $15^0$ face angle is used. Test setup for performance test consists of the following components:



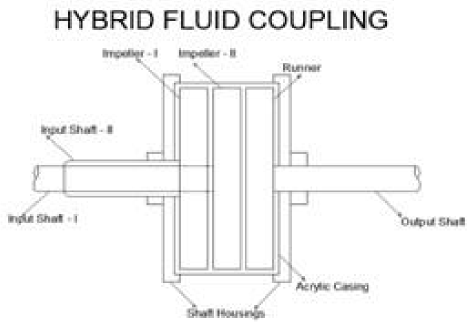




**Fig 1. Test setup arrangement Fig 2. Hybrid Fluid Coupling (Line Diagram)**

**Motor:** The electric motor worked as prime mover for test model. Technical specifications of the motor are as follows

| | |
|---|---|
| Input Power of the Motor-1 | 0.5 HP |
| Number of poles | 4 |
| Speed | 1500 RPM |
| Power Factor | 0.85 |
| Frequency | 50 Hz |
| No of phase | Single Phase |
| Rated voltage | 240 V |
| Rated current | 3.0 A |
| Input Power of the Motor-2 | 0.25 HP |
| Number of poles | 4 |
| Speed | 1500 RPM |
| Power Factor | 0.85 |
| Frequency | 50 Hz |
| No of phase | Single Phase |
| Rated voltage | 240 V |

Rated current 3.0 A

**Brake Drum Dynamometer:** Design specifications of the dynamometer are as follows

Speed Upto 1500 RPM

Type Brake Dynamometer-Belt

Cooling Water cooled

Brake Drum Diameter 120 mm

Belt thickness 6mm

**Fluid Coupling:** The fluid coupling used in this experiment is made of mild steel and its ratings are as follows.

**1. Impellers/Runner:**

Outer Diameter 127mm

Dia of Impeller Eye 65mm

No. of Vanes 24

Length of Vane 31mm

Width of Vane 10mm

Thickness of Vane 1.5mm

Face Angle of the Vane $15^0$

**2. Casing (Acrylic)**

Outer Diameter 139mm

Inner Diameter 130mm

Thickness 5mm

Length 49mm

**3. Shaft (Impeller and Runner)**

Length 140mm

Outer Diameter 17mm

**4. Impeller/ Runner Housing**

Outer Diameter 170mm

Inner Diameter 130mm

Groove depth 5mm

**Working Fluid:** The viscosity grade of lube oil (Fluid) is determined by the Society of Automotive Engineers (SAE). Oils can be separated into multigrade oils and monograde oils. Multigrade oils must fulfill two viscosity specifications, their viscosity grade consists of two numbers, e.g. 10W-40: 10W refers to the low-temperature viscosity ("Winter"), 40 refers to the high-temperature viscosity ("Summer"). Currently, most automotive engine oils are multigrade oils. The oil used should be antioxidant and anti-foaming.

The properties of oils like viscosity, density, ISO Grade and equivalent SAE Grade are given in table-1.

Table-1: Kinematic Viscosity for different ISO Grade oils with equivalent SAE Grade

| **ISO Grade** | **Equivalent SAE Grade** | **Kinematic Viscosity (*centiStokes*)** | | **Density (*kg/m³*)** |
|---|---|---|---|---|
| | | ***40 °C*** | ***100 °C*** | |
| 32 | 10 | 32 | 5.4 | 857 |
| 46 | 20 | 46 | 6.8 | 861 |
| 150 | 40 | 150 | 15 | 872 |

**3. TAGUCHI METHOD:** The Taguchi technique includes the following steps:

- Determine the control factors,
- Determine the levels belonging to each control factor and select the appropriate orthogonal array,
- Assign the control factors to the selected orthogonal matrix and conduct the experiments,
- Analyze data and determine the optimal levels of control factors,
- Perform the confirmation experiments and obtain the confidence interval,
- Improve the quality characteristics.

The Taguchi method uses a loss function to determine the quality characteristics. Loss function values are also converted to a signal-to-noise (S/N) ratio (η). In general, there are three different quality characteristics in S/N ratio analysis, namely "Nominal is the best", "Bigger is the better" and "Smaller is the better". For each level of process parameters, signal-to-noise ratio is calculated based on S/N analysis.

### 3.1. SELECTION OF CONTROL FACTORS AND ORTHOGONAL ARRAY:

In this study viscosity of Fluids, Filled Capacity and Input Power was selected as control factors and their levels were determined as shown in the Table 2.

**Table-2: Control factors and their levels**

| Control Factors | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| Viscosity of Fluids | SAE 40 | SAE 20 | SAE 10 |
| Filled Capacity (%) | 70 | 80 | 90 |
| Input Power (W) | 218 | 220 | 222 |

The first step of the Taguchi method is to select an appropriate orthogonal array. The most appropriate orthogonal array, L9 was selected to determine the optimal power transmission parameters based on the total degree of freedom (DOF) and to analyze the effects of these parameters. The L9 orthogonal array has eight DOF and can handle three level design parameter. The L9 orthogonal array is as shown in the Table 3.

**Table-3: L9 Orthogonal array of Taguchi**

| Experiment No. | P1 | P2 | P3 |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
| 5 | 2 | 2 | 3 |
| 6 | 2 | 3 | 1 |
| 7 | 3 | 1 | 3 |
| 8 | 3 | 2 | 1 |
| 9 | 3 | 3 | 2 |

### 3.2. ANALYSIS AND DISCUSSION OF EXPERIMENTAL RESULTS:

Table 4 shows the experiment results for the output power and corresponding S/N ratios were obtained with the help of Qualitek- 4 software.

### 3.3. CAUSE OF VISCOSITY OF FLUID, FILLED CAPACITY AND INPUT POWER ON OUTPUT POWER

From the response Table 4 and Fig.3 it is clear that Input Power is the most influencing factor followed by

Filled Capacity and Viscosity of Fluid for Output Power. The optimum for Output Power is Input Power of 220 W, Filled Capacity of 90% and Viscous Fluid of SAE 10.

**Table 4: Output power values and corresponding S/N ratio's values for the experiments**

| Trail No. | Viscosity of Fluid | Filled Capacity (%) | Input Powe (W) | Output Power (W) | | | Mean Output Power | S/N Ratio |
|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | | |
| 1 | SAE 40 | 70 | 218 | 93.8 | 95 | 95.8 | 94.89 | 39.54 |
| 2 | SAE 40 | 80 | 220 | 121.2 | 122 | 122.1 | 121.77 | 41.71 |
| 3 | SAE 40 | 90 | 222 | 68.8 | 69 | 69.3 | 69.03 | 36.78 |
| 4 | SAE 20 | 70 | 220 | 133.1 | 132 | 131.1 | 132.07 | 42.42 |
| 5 | SAE 20 | 80 | 222 | 66.4 | 67 | 67.8 | 67.07 | 36.53 |
| 6 | SAE 20 | 90 | 218 | 131.6 | 132 | 132.5 | 132.03 | 42.41 |
| 7 | SAE 10 | 70 | 222 | 59.7 | 60 | 60.3 | 60 | 35.56 |
| 8 | SAE 10 | 80 | 218 | 114.9 | 115 | 115.4 | 115.1 | 41.22 |
| 9 | SAE 10 | 90 | 220 | 187.9 | 189 | 189.8 | 188.9 | 45.52 |

Output power response for each level of the process parameters for Mean (Bigger is the Better)

**Table -5: Output Power response for each level of the process parameters**

| Level | Viscosity of Fluid | Filled Capacity | Input Power |
|---|---|---|---|
| 1 | 95.22 | 95.64 | 114.0 |
| 2 | 110.39 | 101.31 | 147.38 |
| 3 | 121.33 | 129.99 | 65.37 |
| Rank | 3 | 3 | 2 |

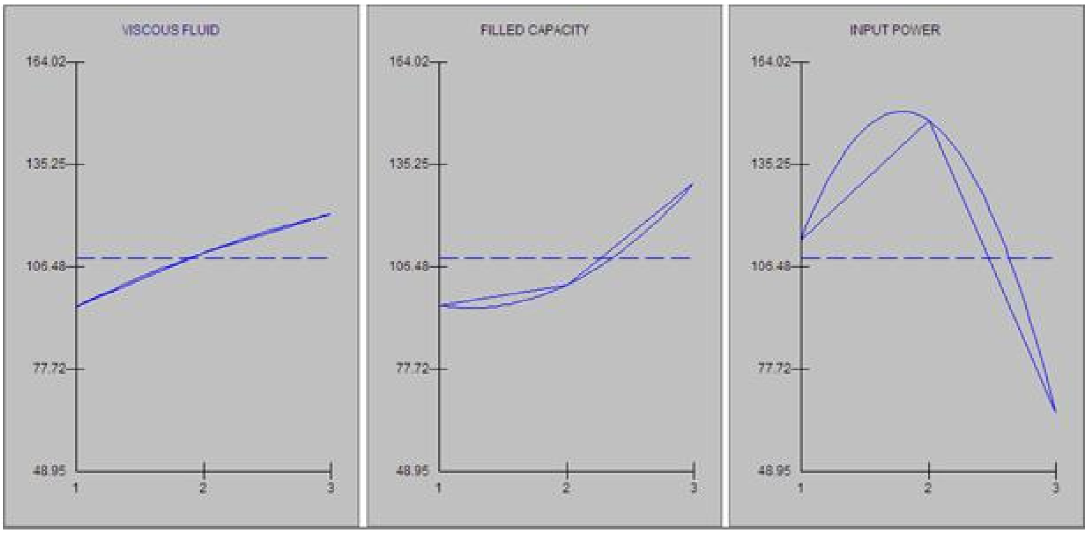



**Fig-3: Main Effects Plot for Mean**

### 3.4. SIGNAL-TO-NOISE RATIO:

The bigger-the-better quality characteristics in analysis of the signal-to-noise ratio was used for this experimental results. The maximum the power rate was the expectation that should be obtained at the end to find out the optimum design and most effective parameter that could

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maximize the power generation. The formula given in the Taguchi method:-

$$\eta = -10\log\left[\frac{[\sum_{i=1}^{n} Y_i^2]}{N}\right]$$

Where Y*i* was the result obtained with respect to *ith* number of experiment, n was the number of experiment and N was the total number of experiments, was used to calculate the signal-to-noise ratio. Table 5 and Fig. 2 illustrated the signal-to-noise ratio of experimental results and its plotted graph respectively.

Output power response for each level of the process parameters for S/N ratio (Bigger is the Better)

**Table-6: Output Power response for each level of the process parameters**

| Level | Viscousity of Fluid | Filling | Input Power |
|---|---|---|---|
| 1 | 39.34 | 39.17 | 41.06 |
| 2 | 40.45 | 39.82 | 43.22 |
| 3 | 40.77 | 41.57 | 36.29 |
| Rank | 3 | 3 | 2 |

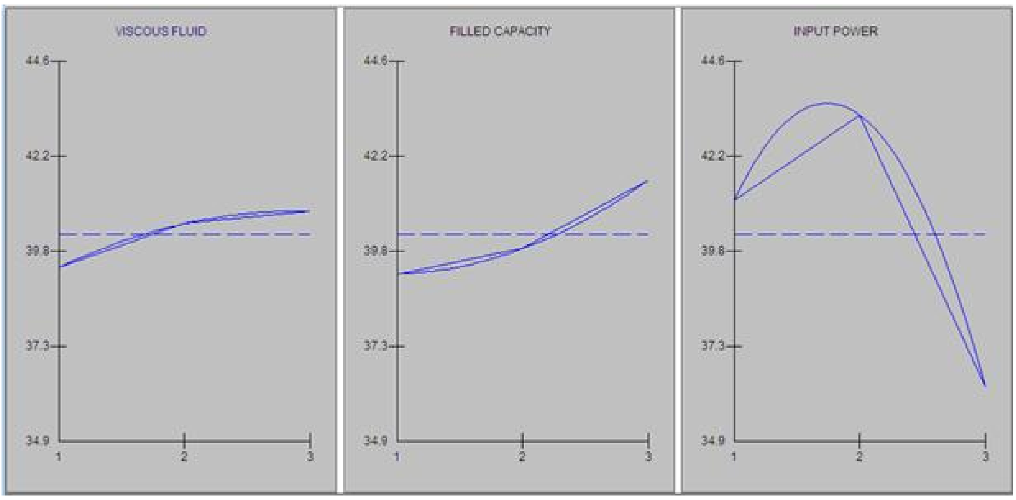


**Fig-4: Fig-3: Main Effects Plot for S/N Ratios**

**3.5.ANALYSIS OF VARIANCE (ANOVA):** Taguchi method cannot judge and determine effect of individual parameters on entire process. The results were analyzed using ANOVA for identifying the significant factors affecting the performance measures. The Analysis of Variance (ANOVA) is to investigate the design parameters and to indicate which parameters are significantly affecting the output parameters. In the analysis the sum of squares and variance are calculated. An F-test value at 95 % confidence level is used to decide the significant factors affecting the process. Larger F- value indicates that the variation of process parameters makes a big change on the performance

**Table-7: Analysis of variance (ANOVA) results for the Output Power**

| Source of variation | DOF | Sum of squares (SS) | Variance (V) | F-Ratio (F) | P-value (P) | Percentage % |
|---|---|---|---|---|---|---|
| Fluid | 2 | 3.36 | 1.68 | 5.439 | 2.742 | 3.095 |
| Filled Capacity | 2 | 9.25 | 4.625 | 14.973 | 8.632 | 9.745 |
| Input Power | 2 | 75.353 | 37.676 | 121.972 | 74.735 | 84.368 |
| Other/Error | 2 | .617 | .308 | | | 2.792 |
| Total | 8 | 88.582 | | | | 100.00% |

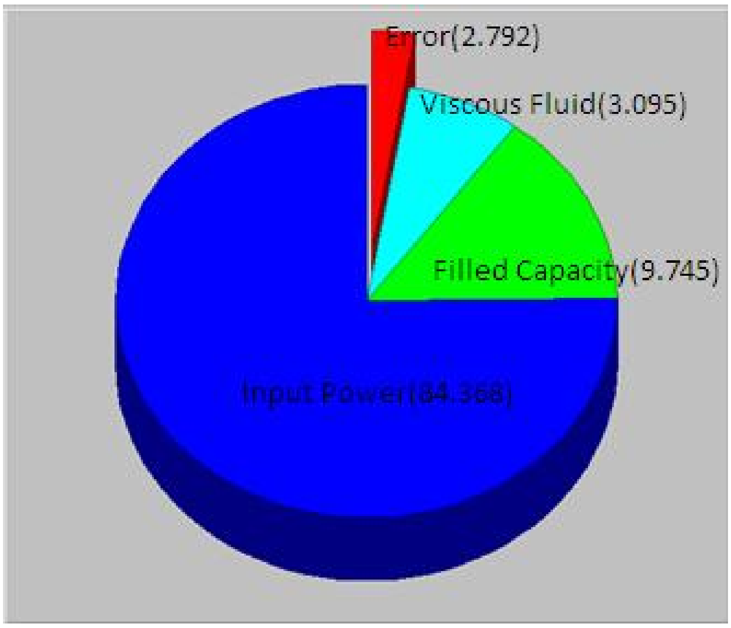


**Fig-5: Significant factor and Interaction Influences**

### 3.6. CONFIRMATION EXPERIMENT:

In order to validate the result obtained, three confirmation experiment were conducted at the optimum setting of the process parameter of Output Power. The Output Power for the Hybrid Fluid Coupling was set at the Third level of Viscous Fluid is SAE 10, the third level of Filled Capacity is 90% and The second level of Input Power is 220 Watts.. The experimental values of Output Power Hybrid Fluid Coupling was found 180.8 Watts, which was with in the confidence interval of predicted optimal.

## 4. CONCLUSIONS:

1. The optimum conditions obtained from Taguchi method for optimizing Output Power during power transmission of Hybrid Fluid Coupling are Viscous Fluid of SAE 10, Filled Capacity of 90% and Input Power of 220 Watts.
2. From response table for Mean of Output Power, it is clear that Input Power of 220 Watts is the most significant factor influencing Output Power followed by 90% Filled Capacity and Viscous Fluid SAE 10 is the least significant factor.
3. Analysis of Variances (ANOVA) for S/N ratio for Output Power of Hybrid Fluid Coupling clearly indicates that the Input Power of 220 Watts is majorly contributing of about 84.368% in obtaining optimal Output Power followed by 90% Filled Capacity 9.745% and Viscous Fluid SAE 10 is 3.095%.
4. Optimum conditions for optimizing Output Power are Viscousity of Fluid of SAE 10, Filled Capacity of 90% and Input Power of 220 Watts
5. From response table for S/N ratio of Output Power, it is clear that Input Power of 220 Watts is the most significant factor influencing Output Power followed by 90% Filled Capacity and Viscous Fluid SAE 10 is the least significant factor.

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