

# Determination of Fatigue Life of Sintered Inner Ring Used In Multicone Synchronesh Transmissions

N. S. Gorre<sup>1</sup>, H. D. Lagdive<sup>2</sup>

<sup>1</sup>M.E. Student, Mechanical Engineering Department, N.B.Navale Sinhgad College of Engineering, Solapur, Maharashtra, India

<sup>2</sup>Associate Professor, Mechanical Engineering Department, N.B.Navale Sinhgad College of Engineering, Solapur, Maharashtra, India

\*\*\*

**Abstract** - A Reaction Cone is one of the key components of Multi cone Synchronizer System. Structural steel is used for manufacturing the Reaction Cone with forging route. The objective of this paper was to achieve a cost reduction by replacing the Process and Material of Reaction Cone. Here structural steel is replaced by Sintered Steel and hence Conventional forging route is replaced by Sintering route. Based on the properties required, 3 grades of sintered steel selected for production. Based on the comparative study, Distaloy AB finalized for production. Slight modifications done in component as per sintering process. FEA analysis conducted for static loading found no concern. Transmission Rig durability conducted as per defined DVP to validate the sintered Reaction Cone as a functional test. Satisfactory results obtained in the test. Based on the results of FEA, Rig durability, Sintered Reaction Cones are said to be validated for the desired function. Preliminary calculations shown 30% cost reduction after implementing the sintered Reaction Cone.

**Key Words:** Design Verification Plan, Multi Cone Synchronizer System, Reaction Cone, Rig Durability, Sintering.

## 1. INTRODUCTION

The transmission system is one of the main parts of an automobile that determines the behaviour, power and fuel economy of the vehicle. Transmission performance is usually related to gear efficiency, gear noise and gear shift comfort during gear change.

Synchronizer mechanisms were developed in the 1920s to allow gear changing in a smooth way, noiseless and without vibrations both for the durability of the transmission and the comfort for the users [1]. What is sought is dynamic shift quality, by means of reduced shifting time and shift effort; especially in heavy truck applications since the torques in the drive train are larger.

Now a day's, Multi cone synchronizer system is well known for smooth gear shifting. Reaction Cone is one of the components of Multi Cone Synchronizer system. Plays a vital role in synchronization phase of gear shift. Conventional way of processing reaction cone is forging route with structural steel as material. This paper present the application of

sintering process and sintered steel as cost effective way of production without compromising the quality.

## 2. LITERATURE REVIEW

Khollam S. C. [2] et. al. explained about the mathematical model for cone angle optimization of the brass type single cone synchronizer ring. A mathematical model was developed in Matlab optimization tool box to select optimum synchronizer parameter. LCV 9 ton, 5 speed manual gearbox with brass type single synchronizer vehicle was considered. Vehicle specification and required parameter like Torque-rpm characteristics, clutch drag, rotating components inertia till synchro was noted. Available synchronizer was measured for improvement. Objective and Constraints function were built and related function was correlated to parameter which has to optimize. Objective function was formed which has to be satisfy in-equality and size & angle parameters, material and comfort limits. For optimization Pattern-Search minimization solver was used in Matlab, which gives global minimum value. Practically this angle varies in the range of 6 to 7.5° for Brass type synchro ring and that of Index angle varies between 105° to 115°, these values together with size effects Cone and index torque. Research directed towards the mathematical modeling of whole synchro pack including each element of synchronizer system.

In "Development of Compact Synchronizer Technology for Manual and Automated Transmissions" Mr. Abhijit Pingale [3] explained about the compact synchronizer system. This paper is focused on some of the key challenges in modern synchronized transmission, and way forward to address those. Some of the key areas delivering highest impact are discussed. A brief description given on combination of various techniques enabling a significant reduction in overall transmission length along with enhancement in shift effort, life and overall performance.

"Modelling of the Gear changing Behavior" Laszlo Lovas [4] et. al. described the working phases of a synchronizer during gear shifting process. Important mechanical parameters are taken into account to correlate the synchronizer behavior. Numerical simulation software's designed to enable in a consistent way the study of parameter influence. Detailed study of the so called double bump effect was presented, and

its components: the force component to release sticking and the turning force were discussed. Taking into account the random nature of this double bump force component, comparative study was carried out between measured and calculated force values.

A review giving application, features and limitations of the current level of technology is presented. In addition, the system performance malfunction and possible reasons there off are addressed by Umesh Wazir [5] in his literature "Manual Gearbox Synchronizers: An Overview". This paper very similar to the first paper listed in this review. He contributed in the field of synchronizer performance and malfunction; He simplified the assumptions of the gear shifting events in order to facilitate the performance understanding. Detail summary is given about the effects of geometry on synchronizer performance and effect of materials on synchronizer performance. Different material combinations are summarized for optimum performance of synchronizer. The literature ended with the future direction towards new materials and new processing methods. One such method is sintering route to produce components and minimize machining. Hint is also given towards the development of new friction linings to optimize the cone angle.

"Manual Transmission Synchronizers" is treated as a basic literature for the researcher studying the synchronizer system. In this paper Mr. Richard Socin and L Walters [6] explained the basics of synchronizer system. Briefed on rotational inertia and reflected inertia. Mathematical relationship established for the performance of single cone synchronizer system. Performance malfunctions and symptoms are summarized in later section. Effect of material, lubricant, geometry changes, friction surfaces on the performance of the synchronizer system is explained in brief. Design basics for different component of the synchronizers system discussed briefly. Detail note given on drag torque and its impact on the performance of synchronizer system. Different testing methods for evaluation of durability of synchronizer system discussed briefly at the end. In summary it was a review related to synchronizer system and its performance.

Maximilian STREBEL [7] et. al. briefed about the drag torque behavior of the manual transmission synchronizers. Between the friction surfaces of synchronizers there is an air lubricant mixture, which generates a drag torque under rotational speed differences. The higher the amount of lubricant between the friction surfaces, the higher the drag torque is. Details of test rig for measurement of synchronizer drag torque explained in this literature. Also calculation method for synchronization drag torque is mentioned and concluded the literature with three possible ways to reduce the drag torque of synchronizers.

"Applicability of the New Kyowa High Performance Synchronizer" by Hackel Thomas [8] et. al. focused on the

shift effort during synchronization as main influence. He introduced a new concept, the Kyowa High Performance (Hi-Per) Synchronizer (KHS). This paper provides information about the design calculations and test bench results at all important working conditions. Future scope is directed towards the development of Multi Cone KHS.

In "Innovative Solutions for Synchronizer Systems", Ottmar Back [9] briefed about Smart Key Synchronizer (SKS) system replacing the proven Borg Warner synchronizer system. In the SKS, the function of the outer ring is limited to the rpm synchronization and the indexing of the SKS unit. The new SKS unit does the blocking function. The elimination of the blocking teeth at the outer ring makes it possible to design the roofing of the sleeve teeth systematically for the engagement with the index teeth. The roofing angle can be optimized separately of the blocking function.

Ottamar Back [10] explained the basics of synchronizer system in detail. He has given the overview of variety of driveline concepts, the interfaces of transmission to the vehicle, the interface of the transmission to the driver and installation and the interfaces of the synchronizer in the transmission. Also explained the various types of synchronizer based on the friction surfaces and the different phases of synchronization. The paper elaborated the basics of synchronizer calculation considering different inputs and limiting factors. He explained calculation of different parameters and characteristic values of different parameters. Interface is explained along with functional problems related to synchronizer system and their remedies

Research paper "Application of Sintered Steel for Synchronizer Rings used in Mechanical Transmissions" [11] proposed a solution to the Blocker ring material. This component was primarily designed with a Cu-Zn alloy, had earlier failure on blocker ring teeth during tests. To eliminate this problem several possibilities were analyzed considering the cost and productivity ratio, Use the sintered steel FLC-4908 per MPIF Standard 35. FLC-4908 resulted in higher mechanical properties than brass alloy. It is observed that the life improved in much higher rate than the corresponding increase of mechanical properties, making clear the effect of other characteristics of the sintering at Blocker ring life. From these results, sinter-hardening steel is considered as a material alternative for brass based synchronizer rings that presents same failure mode, since it infinite life observed in the accelerated endurance test.

### 3. OBJECTIVES

A. Development of Reaction Cone through sintering process.  
B. Validation of Sintered Reaction Cone for rig durability (bench test) and functional durability.

C. To achieve cost reduction through material and process change.

#### 4. PROBLEM STATEMENT

A. Reaction Cone used in multi cone synchronizer system is made up from forging route with material as low carbon steel.

B. The manufacturing processes shown below

- Forging
- Blanking
- Heat Treatment
- Finish Machining

C. Each process is having its own cycle time of processing and prone to rejection if due care is not taken.

D. Line stoppage issues happened due to non-availability of material in time hence heavy inventory levels are to be maintained to avoid such concerns.

E. A new process is to be established for Reaction Cone to overcome the above stated issues.

F. Reaction Cone developed from new process is to be validated for static loading and functional durability.

#### 5. METHODOLOGY

The methodology used in the presented work is explained in steps as below:

A. Selection of Manufacturing Process:

In this step, the optimized process is selected based on the problem statement. Here we have selected Sintering process for manufacturing of Reaction Cone as it is productive and cost effective.

B. Selection of material:

Number of sintered materials is available in the market now a day. The material is selected based on the final requirement of the product and ease in manufacturing during intermittent process. Based on this criterion, Distaloy AB material is selected for the processing of Reaction Cone.

C. FEA Analysis for static Loading

As stated earlier, FEA Analysis is conducted to evaluate the component performance under static loading. Here analysis is done with help of ANSYS 13.0 in static structural mode. Details of analysis explained stepwise.

##### 5.1. Material:

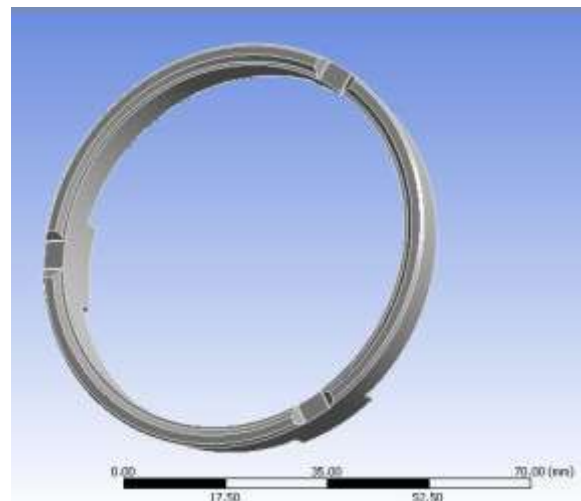
As the selected material is Distaloy AB, concerned properties are taken for analysis.

Following are the material properties (MPIF Standard 35)

- Sinter Hardened Powder Metal : Distaloy AB
- Core Strength : 650 N/mm<sup>2</sup>
- Minimum Hardness : 1176 N/mm<sup>2</sup> (37 HRC)
- Poisson's Ratio : 0.27
- Density : 7 g/cm<sup>3</sup>
- Young's Modulus : 130000 N/mm<sup>2</sup>

##### 5.2. Part Geometry:

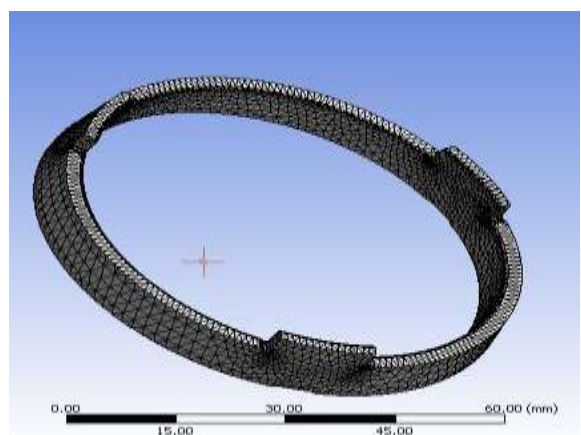
Component modelling is done UG NX 9. Then the file is converted into STEP format for importing in ANSYS.



**Fig -1:** shows the model imported in ANSYS 13.0.

##### 5.3 Meshing:

Standard quadratic mesh type is selected with mesh size 0.5 mm for analysis. There is scope of mesh refinement near the area of maximum stress. Fig 2 shows the meshing of component.



**Fig -2:** Meshing

### 5.4 Loading Condition:

In actual testing load of 100 N applied at shift knob. Then the load is transferred to Reaction Cone with the multiplication of lever ratio.

Since the load is applicable at the 3 lugs, it should be uniform. Hence the force is converted into uniform pressure acting at the contact area of the 3 lugs.

Contact Area of lug = Length X Thickness

(Values taken from component drawing)

$$= 3.48 \times 4.4 = 15.312 \text{ mm}^2$$

Lever Ratio: 7 (For NGT Transmission)

Therefore,

Total load at lug area

$$= \text{Handball Effort} \times \text{Lever Ratio}$$

$$= 100 \text{ N} \times 7 = 700 \text{ N}$$

The uniform pressure at the tree lugs can be calculated as

$$\text{Pressure} = \text{Force} / \text{Area}$$

$$= 700 / 15.312 = 45.7157 \text{ N/mm}^2$$

$$= 46 \text{ N/mm}^2 \text{ or } 46 \text{ MPa}$$

Fig 3 shows the loading pattern of the component.

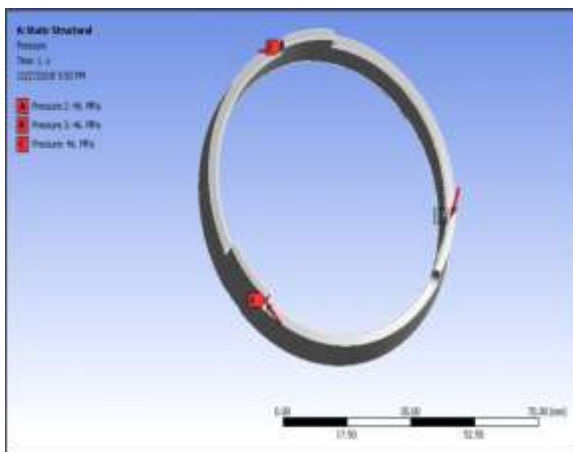


Fig -3: Loading Pattern

### 5.5 Boundary Conditions:

Zero axial displacement constraint is applied at thrust face of Reaction Cone as there is no axial movement of Reaction Cone during synchronization phase.

The second constraint is fixed constraint at cone surface as it remains stable during synchronization.

Hence both constrain simulates the actual condition of component during synchronization. Fig 4 shows the boundary conditions of component.

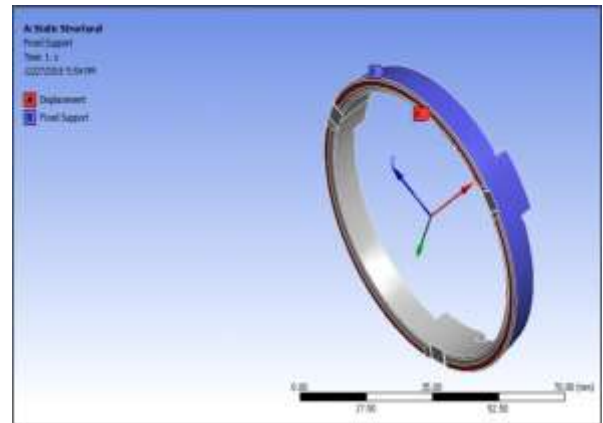


Fig -4: Boundary Conditions

## 6. RESULTS

Von-Mises stress is taken as result. Fig -5 shows the result

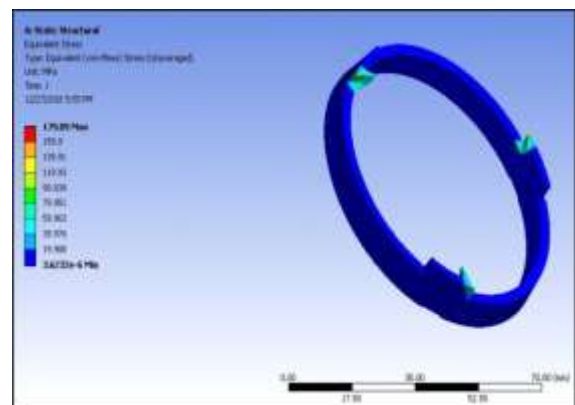


Fig -5: Result of Analysis

From the above result, it can be seen that the maximum Von-Mises stress is at the edge of the lug and is concentrated at very low region.

The value of maximum stress is 179.89 MPa (180 MPa approx.).

Hence the factor of safety for the given component can be calculated as

$$\text{Factor of Safety} = \text{Material Strength} / \text{Design Strength}$$

From the material properties, Material Strength is 37 HRC or 1176 N/mm<sup>2</sup> (1176 MPa)

Therefore the factor of safety will be

Factor of Safety = 1176 / 180  
= 6.53.

As the factor of safety is 6.53 for given condition of loading, It can be said that the component is safe in static loading condition with material as Distaloy AB. That is sintered material is safe for the given geometry of component and for given condition of loading. D. Receipt of Sample Product:

Based on the clearance from FEA and manufacturing development. Sample parts are produced for validation testing. Layout inspection of sample part is done prior sending to testing.



**Fig -6:** Sintered Reaction Cone

**6.1 Functional testing:**

**6.1.1 Introduction:**

The synchronizers to be tested for durability are to be assembled in the respective transmission, and then transmission has to be tested for its durability with required gear shift sequence for its designated test cycles.

It should be tested with the inertia mass (vehicle inertia) on the output shaft and free clutch disc on input side. Power is given from output shaft of transmission by electric motor and required rpm is monitored as per detail test specification.

**6.1.2 Objective:**

Objective of the test is to understand deterioration of shift effort and measure synchronizers wear after desired life cycles tests.

**6.1.3 Test Specification:**

The Test Specimen, transmission has to be put to different gear shift sequence as mentioned in the organizational Design Verification Plan (DVP). The DVP is based on the functional requirement of product and final application of product. Hence it varies organization to organization and application to application.

Following is the DVP for NGT Transmission where the modified Reaction Cones are to be assembled for durability testing.

Sr. No.	Gear Change Cycle	No. of Cycles	Load at Shift Knob	Cycles Per Min	I/P RPM
1	1-2-1	75000	100 N	8 - 9	1200
2	2-3-2	150000	100 N	11- 13	3500

Note: As the modified Reaction Cone fits at 1st/2nd Position only those positions are tested for rig durability

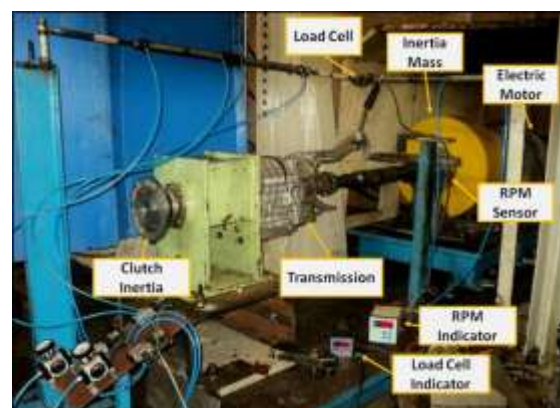
**6.1.4 Test Equipments:**

Following Equipments were used for conducting the Test

- i. Electric Motor: 25 Hp 2880 rpm.
- ii. Pneumatic Actuator: 3 Nos., Bore=25 mm, Piston rod Diameter =10 mm, Stroke=200 mm.
- iii. Pressure Gauge: 2 Nos., 0 to 16 bar.
- iv. Direction Control Valve: 3 Nos., 5/3 X 1/8 Single Acting with Solenoid Coil
- v. Load Cell: 100 Kg

**6.1.5 Test Setup Images:**

The test setup for transmission synchronizer durability test is shown below with the help of photographs (Fig 7 and Fig 8). This will give general idea about the test set up. This set up will change according to the transmission type and shift pattern. But the basic equipments and accessories required to run the testing are same.



**Fig -7:** General Setup of Transmission Synchronizer Durability Test

### 6.1.6 Test Procedure:

- i. Test setup as per photographs (Fig 7 and Fig 8).
- ii. Start the motor with calculated rpm (as per the gear ratio).
- iii. Then, release the required pressure to the pneumatic actuator for gear shift (based on the effort required at shift knob refer DVP).
- iv. Measure gear shift effort by load cell for initial 10-20 shifts.
- v. Repeat the same exercise to measure gear shift effort by load cell at the end of test cycles.



Fig -8: General Setup of Transmission Synchronizer Durability Test

### 6.1.7 OBSERVATIONS:

Following Checks were carried out during & after completion of the Test.

- i. Malfunctioning noise in the gear box.
- ii. External damages if any during the testing.
- iii. Inspection of the Synchronizers before and after test.

### 6.1.8 Results:

- i. Transmission shift durability test is completed as per the explained procedure and corresponding DVP.
- ii. No abnormal noise observed during and after completion of test.
- iii. No significant deterioration observed in the shift force while shifting either gears.

iv. Cone Gauge Dimension wear observed as 0.009 mm as against acceptable value of wear 0.05 mm. Hence the wear is within limit.

v. From these results part is said to be validated. Another test is planned to have better information on the performance of the Reaction Cone.

### 7. COST REDUCTION

Below table shows the calculations of cost reduction. This calculation is based on the per piece cost of reaction cone. Here tooling cost in either process is not considered.

Sr. No.	Processing Route	Net cost (INR)
1	Forging (Existing)	130.475 (1.535 Euro)
2	Sintering (New)	90.57
	Per Piece Difference	39.905

Therefore achieved cost reduction can be calculated as

$$\begin{aligned} \% \text{ Cost Reduction} &= 39.905 / 130.475 \times 100 \\ &= 30.5840 \end{aligned}$$

### 8. CONCLUSION

Based on the cost benefit analysis, sintering is selected for processing of Reaction Cone. Distaloy AB is finalized based on the comparative study of functional parameters. Additionally FEA is conducted to verify the static loading condition. Part found safe in static loading. Factor of safety observed as 6.53. Part is subjected to functional validation. Rig validation is preferred for functional validation as per desired DVP. Wear of Gauge Dimension (Cone Diameter) found within specified wear limit i.e. 0.009 mm as against 0.05 specified. No deterioration of Cone Angle and Cone Roundness observed. Based on the results of the test, part is said to be validated for desired function. Another testing is planned to gain additional confidence. Part is implemented in the production based on the acceptance. From preliminary calculations it is seen that cost reduction of 30.58% is achieved. Detail study of sintering productivity needed in order to have an exact value of cost reduction. This method can be used for manufacturing of other parts of transmission synchronizer system. One of such part is intermediate ring.

### ACKNOWLEDGEMENT

Author would like to thank to my guide Prof. H.D.Lagdive, asst. professor, Prof. K.S. Mangrulkar, ME Coordinator, Dr. S.D.Nawale, Principal, N.B.Navale Sinhgad College of Engg., Solapur for their guidance during this work. Author is also thankful to M/S Divgi TorqTransmission Pvt Ltd, Pune for the

support during the part manufacturing and experimental testing.

## REFERENCES

- [1] G. Lechner, H. Naunheimer, Automotive transmissions: fundamentals, selection, design and application. Berlin: Springer (2010).M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.
- [2] Kholam.S.C, Mhaske M S, Belkar S B, Method to Optimize Brass Type Single Synchronizer Ring for Manual Gearbox, International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-3, Issue-3, February 2014
- [3] Abhijeet Pingale, Development of Compact Synchronizer Technology for Manual and Automated Transmissions, SAE Technical Paper 2014- 01-1719, 2014.
- [4] László Lovas, Daniel Play, János Márialigeti, Jean-François Rigal, Modelling Of Gear Changing Behaviour, Periodica Polytechnica Ser. Transp. Eng. Vol. 34, No. 1–2, Pp. 35–58 (2006)
- [5] Umesh Wazir, Manual Gearbox Synchronizers – An Overview, International Journal of Emerging trends in Engineering and Development Issue 3, Vol.5, September 2013.
- [6] Socin, R J. and Walters, Manual Transmission Synchronizers, L.K., SAE 680009.
- [7] Maximilian Strebel, Michael Wirth, Hermann Pflaum, Karstel Stahl, The Drag Torque Behaviour Of Manual Transmission Synchronizers, STLE Annual Meeting may 17th-21st, 2015 Dallas, Texas, USA, 2015
- [8] Hackl, Thomas, Ed., Applicability of The New Kyowa High Performance Synchronizer, F2006P097T
- [9] Ottmar Back, Erol Ledetzky, Peter Ehtler, Innovative Solutions for Synchronizer Systems
- [10] Ottmar Back, Basics of Synchronizers, 2013
- [11] Andrade, T.F, Zambon, A.C., Sena, C.H.C., Bida, A.G., Kawai, J.R., Application of Sintered Steel for Synchronizer Rings used in Mechanical Transmissions, Materials Science Forum Vols. 727-728 (2012) pp 349- 355