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OPTIMIZING PROCESS DESIGN TO ENHANCE VEHICLE BRAKING EFFICIENCY

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ABSTRACT

A brake system for a heavy vehicle or passenger vehicle is an extremely delicate one and very important for safety. Efficiency braking system depends on function of sub-assemblies like Vacuum booster, Master cylinders, Disc brake assembly & Brake lines. Rubber diaphragm is the significant child part of vacuum booster sub assembly of braking system. Study aims in optimizing process design & improve detection control of rubber diaphragm manufacturing process across the sources to enhance vehicle braking efficiency, safety & product reliability. Key trigger for this project is customer warranty issues like hard braking & discomfort during apply of brake. To achieve the goal study conducted to understand the manufacturing process of rubber diaphragm and to find out probable root cause for customer warranty issues through the application of analysis techniques and statistical problem solving tools like Benchmarking study, FMEA, Poka Yoke, Process automation, Process parameters study, Product validation & Data analysis. Process is more significant than controlling product characteristics. A challenge is on deploying process design optimization plan across the different sources – Technology advancement & cost impact. Since sources adapting to different technology like manual, semi automatic & fully automatic process.

Keywords: Rubber Diaphragm, Vacuum booster, Vehicle Brake, Optimizing process design, Product feature matrix, Process Improvement plan & Root cause analysis.

INTRODUCTION

A vehicle brake is used to slow down a vehicle by converting the kinetic energy into heat energy. The basic hydraulic system, most commonly used, usually has six main stages: the brake pedal, the brake boost (vacuum servo), the master cylinder, the apportioning valves, and finally the road wheel brakes themselves.

Provide a means of using friction to slow, stop, or hold the wheels of a vehicle, when a car is moving, it has kinetic energy (inertia), to stop the vehicle, and the brakes convert mechanical (moving) energy into heat. To stop the vehicle, the brakes convert mechanical (moving) energy into heat.

Brake Operation: When the driver pushes on the brake pedal, lever action pushes a rod into the brake booster and master cylinder, the pressure developed in the master cylinder forces fluid through the brake lines to the wheel brake assemblies & the brake assemblies use this pressure to cause friction for braking. Drum brake - A drum brake is a vehicle brake in which the friction is caused by a set of brake shoes that press against the inner surface of a rotating drum. The drum is connected to the rotating road wheel hub. Disc brake - The disc brake is a device for slowing or stopping the rotation of a road wheel. A brake disc usually made of cast iron or ceramic is connected to the wheel or the axle. To stop the wheel, friction material in the form of brake pads is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop.

Power Assisted Brake: Most all modern vehicles use power assisted brakes, A vacuum line from the intake manifold to the brake booster provides a source of vacuum and a brake booster check valve prevents loss of vacuum during wide open throttle, Vacuum in the intake manifold is applied to a rubber diaphragm on the vacuum side of the booster chamber (red speckled area). Vacuum booster - Uses vacuum produced in the engine intake manifold or by a separate pump to apply the hydraulic brake system, Consists of a housing that encloses a diaphragm, when vacuum is applied to one side of the booster, the diaphragm moves toward the low-pressure area. Use a booster and vacuum or hydraulic pressure to assist brake pedal application, booster is located between the brake pedal linkage and the master cylinder, when the driver presses on the brake pedal, the brake booster helps push on the master cylinder pistons.

Vacuum booster working principle is when the engine is running and the brake are not depressed there is vacuum on both sides the booster diaphragm (vacuum Suspended), as brake is applied atmospheric pressure is allowed to enter the rear of the booster through an air control valve increasing pressure on the master cylinder, when the brake pedal is depressed the air valve moves forward allowing atmospheric pressure to enter the rear of the brake booster assembly, higher pressure in the rear forces the diaphragm to move forward increasing the pressure applied to the master cylinder. A spring in the front chamber forces the diaphragm rearward when the brake pedal is released.

Master Cylinder is foot: Operated pump that forces fluid to the brake lines and wheel cylinders, develops pressure to apply the brakes, equalizes pressure required for braking, and keeps the system full of fluid as the linings wear.

May maintain a slight pressure to keep contaminants from entering the system. Diaphragm is made up with

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Rubber material and manufactured through the molding process. When the brake pedal is depressed the air valve moves forward allowing atmospheric pressure to enter the rear of the brake booster assembly. The higher pressure in the rear forces the diaphragm to move forward increasing the pressure applied to the master cylinder. A spring in the front chamber forces the diaphragm rearward when the brake pedal is released. 2 type of rubber material are used to manufacture the diaphragm Natural rubber (NR) is an agricultural crop

And synthetic rubbers are based on petroleum. Most synthetic rubbers are produced from petroleum by the same polymerization techniques used to synthesize other polymers, unlike thermoplastic and thermosetting polymers, which are normally supplied to the fabricator as pellets or liquid resins, synthetic rubbers are supplied to rubber processors in the form of large bales, the rubber industry has a Manufacturing Process Technology / Molding Processes are compression molding is the process of placing a pre-load of a rubber material or compound directly in the mold cavity and compressed to the shape of the cavity by the closure of the mold. Transfer Molding is the process in which the rubber material or compound is placed in the mold "pot", located between the mold top plate and the press plunger, and the material or compound is squeezed from the "pot" through gates or sprues into the mold cavity. Injection Molding is the process in which the rubber material or compound is heated, and while the material or compound is in a flow able state in the injection barrel, the material or compound is forced or injected into the mold cavity.

DIAPHRAGM MANUFACTURING PROCESS

Compounding Weighing
Mixing (Kneader)
Calendering
Extrude clean
Moulding process
Deflashing
Part Inspection

Compounding: Rubber is always compounded with additives, Compounding adds chemicals for vulcanization, such as sulphur, Additives include fillers which act either to enhance the rubber's mechanical properties or to extend the rubber to reduce cost, it is through compounding that the specific rubber is designed to satisfy a given application in terms of properties, cost, and process ability.

Mixing process: The additives must be thoroughly mixed with the base rubber to achieve uniform dispersion of ingredients, uncured rubbers have high viscosity so mechanical working of the rubber can increase its temperature up to 150 deg. (300 F). If vulcanizing agents were present from the start of mixing, premature vulcanization would result – the "rubber processor's nightmare". To avoid premature vulcanization, a two-stage mixing process is usually employed, carbon black and other non-vulcanizing additives are combined with the raw rubber and the term master batch is used for this first-stage mixture. Stage 2 - after stage 1 mixing has been completed, and time for cooling has been allowed, Stage 2 mixing is carried out in which vulcanizing agents are added.

Extrusion process: Screw extruders are generally used for extrusion of rubber, The L/D ratio of the extruder barrel is less than for thermoplastics, typically in the range 10 to 15, to reduce the risk of premature cross-linking Die swell occurs in rubber extrudates, since the polymer is in a highly plastic condition and exhibits the "memory "property The rubber has not yet been vulcanized.

Calendaring process: Stock is passed through a series of gaps of decreasing size made by a stand of rotating rolls. Rubber sheet thickness determined by final roll gap

DATA ANALYSIS & EXPERIMENTAL

SCOPE FOR POKE YOKE

Table.1.scope of poke yoke

Process	Scope for Poka Yoke
Compounding	1. Chemical Identification & Traceability 2. Eliminate Process skip - During addition of chemicals
Mixing	1. Different chemical batch mix-up
Calendering	1. Strip thickness variation
Moulding process	1. Mold hot spot - cooling channel clogged due temperature variation at die & exit water 2. Avoid accidents during process 3. Detection / Control of Adherence to Standard cycle time
Deflashing	1. Avoid flash during moulding process 2. Detection control of flash
Part Inspection	1. Detection Not Ok / Non conformance?

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Bench marking / best practice

Table.2.scope for deploying best practices

Process	Scope for Benchmarking & Best Practices
Compounding	1. New technology / Equipments 2. Process automation 3. Chemical Identification & Traceability 4. Eliminate Process skip - During addition of chemicals
Mixing (Kneader)	1. Effective process flow 2. Eliminating mix-up of different chemical batches
Calendering	1. Operator Training 2. Strip thickness variation
Extrude clean	1. Machine features / Process parameters
Moulding process	1. Process characteristics 2. Operation sequence 3. Detection control 4. Process automation
Deflashing	1. Avoid flash during moulding process 2. Detection control of flash
Part Inspection	1. Detection of Not Ok / Non conformance?

Warranty / key issues trend

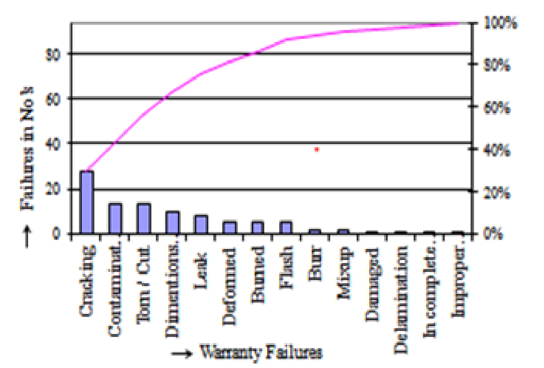

Figure.1.Warranty failure trend

Warranty failure – process wise

Table.3.Matrix - warranty failure vs process

Row Labels	Burrs and flashes	Part Damaged	Short shot	Lable wrong	Dimension NOK	Part Cracked	Not Clear	Schedule not adhered	Part Burning	Scorched	QCCAR in German	Packaging dirty	Blooming effect on diaphragm less	Delamination	Grand Total
04 - Moulding	3	8	5		5	2			3	2				1	29
07 - Packaging & Logistics		3		7				4				1			15
05 - Deflashing	9	2	1			1									13
Not Clear							4								4
QCCAR in German											2				2
External damage- Claim rejected by Supplier			1												1
01 - Rubber compounding													1		1
03 - Extrude Clean						1									1
06 - Part Inspection	1														1
Grand Total	13	13	7	7	5	4	4	4	3	2	2	1	1	1	67

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Failure vs potential root causes:

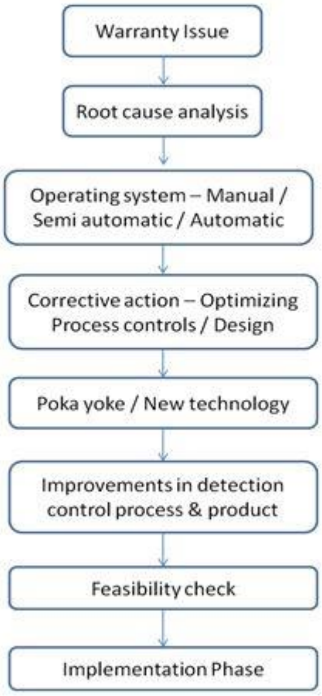
Table.4.Matrix failure vs root cause

Row Labels	Operator Error	Not Clear	Mold cleaning - Difficulty @ Nipple area	Tool life - Exeeded	Process Not Defined	Deflashing - Accidental cut	Cleaning process not established	Machine Error - setting / drift	Deflashing - Incorrect Tool	QCCAR in German	Deflashing - Set up error	RubberShelf life not defined	Deflashing - Operation skipped	Deflashing Tool design / Life	Printer Error	Tool Dimension Error	Deflashing - Manual - Process variation	Contamination - Environment	Mold hot spot - cooling channel clogged	Tool cleaning frequency	External damage- Claim rejected by Supplier	Tool Design - Flash	Less packaging	Recipe error.	Curing in Nozzle	Deflashing - Too hot part	Nipple inversion during demolding	Excess curing time	Contamination - Environment - Rubber	Grand Total
Burrs and flashes		1		1		1		2			1		2	2			1									1			1	13
Part Damaged	4	3	1						1		1	2							1											13
Short shot			3						1											1	1				1					7
Lable wrong	4				2										1															7
Dimension NOK		1		1												1						1					1			5
Part Cracked			1			1	1											1												4
Not Clear		4																												4
Schedule not adhered	3																						1							4
Part Burning			1	1			1																							3
QCCAR in German										2																				2
Packaging dirty					1																									1
Delamination		1																												1
Blooming effect on diaphragm less																								1						1
Scorched																												1		1
Grand Total	11	10	6	3	3	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	66

RESULTS & DISCUSSION

Optimizing process design:

Figure.2.Road map to process design optimization



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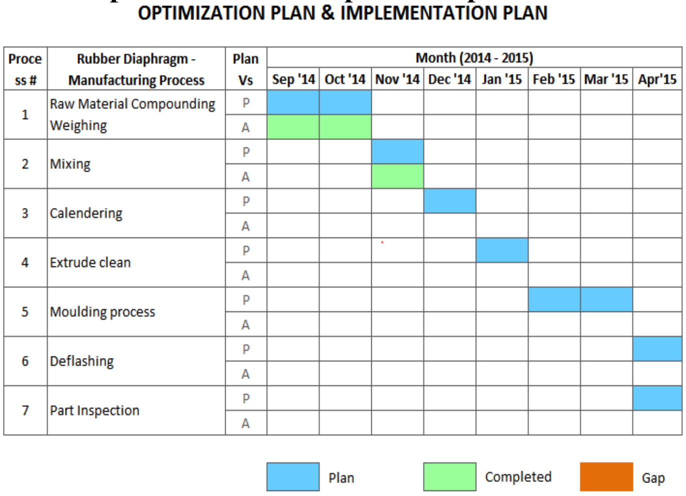
Optimization format:
Format to process qualification master

Process Optimization Plan / Questionnaire Checklist : **Diaphrams**

Supplier Name Location	Read Across Auditor(s) Auditees (Supplier Participants)	Audit Date

Q #	Process Name Failure mode	Root Cause Classification	Evidence Required	Score	Observation	Action Item	Priority	Target
	Rubber compounding							
	Extrude Clean							

Process wise improvement plan:
Implementation time plan for optimization



Raw material compounding weighing:

Rubber compounding - process qualification master

Q #	Process Name Failure mode	Root Cause Classification	Evidence Required
	Rubber compounding		
1	Blooming effect on diaphragm less	Recipe error.	Evidence that the selection & quantification of Oils / Liquid ingredients integrated with the automation available for selection & weighing of Powder / resin based additives / ingredients at both Master batch and Final batch preparation points. **Future State :** Liquid system & Powder systems are integrated. (or) Separate weighing automation exists for Liquids and Powder ingredients, but not integrated.
2	Dimension NOK	Recipe error.	Evidence of ALL "Master Batches" & "Final Batches" being checked for Rheological & Mechanical properties? **Future State :** Mandatory 100% check for Rheology reflecting in Control Plan.

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Extrude clean:

Extrude – process qualification master

Q #	Process Name Failure mode	Root Cause Classification	Evidence Required
	Extrude Clean		
1	Part Cracked	Cleaning process not established	1. Evidence that there are no 'Trap points' in the Barrel, Ram and Die holder, where residue from previous extrusion gets stuck. Evidence that above locations are frequently checked and cleaned? 2. Are appropriate Mesh Size and number of meshes used? 3. How is control exercised on the number of times a mesh is used or when to discard based on visual assessment of the filtrate? Is it backed by a clear Standard operating procedure

CONCLUSION

Based on Road map Warranty Issues are analysed and Interaction matrix has been created between failure mode, process and root cause. Inline to Interaction matrix – Scope of Improvement in process, Process Optimization plan / Process Qualification Master has been generated based on Significant Inputs from process study conducted across the different manufacturing sources. Problem solving / statistical techniques used – Poka Yoke, Parato analysis, FMEA, Benchmarking process, Process Matrix, Data Interpretation & Analysis.

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