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AXIOMATIC DESIGN FOR PROCESS PLANNING IN INJECTION MOULDING PROCESS

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ABSTRACT

Typical development projects for new software, business projects, or products undergo many cycles of the "design-build-test-redesign-build-test" cycle. Under this approach, development decisions are made quickly based on experience and empirical data to reach the 80% completion level relatively quickly. With increasing competition in the market, expediting the problem solving process has become crucial in the industry. Rapid changes in product design, process design and short product life cycle leads to introduction of new products also, increasing global competition requires manufacturing systems to be highly flexible, adaptable and responsive. As such, a number of problem solving techniques have been devised efficiently to tackle problems of varying natures. One of such techniques is Axiomatic Design (AD) has been widely applied in a large range of industries and services. This approach has an edge over the traditional approaches to ensure good results.

In this present work, an attempt is made to apply Axiomatic Design for "process planning" in injection moulding process using DFSSV5 software at Nandi Plasticizers and Pipes Ltd. Nandyal. The Model is developed by using CATIA software.

Keywords: Axiomatic Design, Process Planning, Injection Moulding Process, DFSSV5 software

I INTRODUCTION

One may ask, "Humans have been designing and developing products and services for thousands of years, then why study design methodologies and product development processes?" The answer is that there is a continuous need for new, cost effective, high quality products and a need for better, more structured design and process development Lifecycle models that are based on best practices and scientific principles. Roughly 85% of the problems with new products are the result of poor design. Competitive marketplace is forcing industrial firms develop and deliver higher quality products with increased performance in a shorter time at a lower cost. The other needs are to improve management of project and product development Lifecycle knowledge, and lower the total Lifecycle cost. One of the main reasons why the design and development practices are poor is that the design process is heavily based on experience and trial-and-error more than structured and scientific principles and methodologies. The current process development approaches lack a formal framework and they are not based on scientifically validated design theories and tools. The product development activities are performed heuristically or empirically. The design models should support identifying correct and complete requirements and verifying the design starting from the very early stages in order to reduce the cost and schedule and to satisfy the customer since 80% of the products total cost is committed during the concept development phase. The design models should support communication between the stakeholders in order to achieve high quality products that meet the customer expectations. A survey showed that engineers spend over 70% of their time on communication related activities, suggesting that achieving effective communication between stakeholders during the product development Lifecycle should be a priority of process improvement efforts. The proposed model, called the Axiomatic Product Development Lifecycle, is based on the Axiomatic Design (AD) method developed by Suh (1991); hence it inherits all the benefits of applying AD to product design. The underlying hypothesis of AD is that there exist fundamental principles that govern good design practices. The AD begins with two axioms, the independence and the information axioms. The axioms provide guidelines for design engineers. Dr. Suh provides a number of theorems and corollaries that are developed from the axioms to facilitate their use. The AD method provides a robust structure and systematic thinking to support design activities, however, it does not support the whole product development Lifecycle. The same logic and scientific thinking can be used and extended to capture, analyze, and manage the product development lifecycle knowledge. Plastic materials are commonly used in every area of the industry. The most important reason for this is the material properties of the plastics. Some of these properties are lightness, resistance to corrosion, ease to give shape. The most important is their physical and chemical properties can be changed as desired. Plastic materials can be used in packaging, aerospace, aviation, building and construction, automotive, agriculture, irrigation, sanitation, electrical conduits, and chemical processing plants etc. Plastic Injection Molding (PIM) is considered the most prominent process for mass producing plastic parts. More than one third of all plastic products is made by injection molding, and over half of the world's polymer processing equipment is used for the injection molding process. Plastic injection molding is one of the manufacturing processes carried out by a consecutive five phases with plastication, injection, packing, cooling and ejection. This process is complex but highly efficient means of producing a wide variety of three dimensional thermoplastic parts in a large volume of production. During production, quality problems with the plastic parts such as warpage, shrinkage, weld and meld lines, flow mark, flash, sink mark and void are affected by manufacturing process conditions which include the melt temperature, mold temperature, injection pressure, injection velocity, injection time, packing pressure, packing time, cooking time, cooling temperature etc. One of the most important quality problems is warpage. Warpage, is a distortion of the shape of the final injection-molded item, is caused by differential shrinkage; that is, if one area or direction of the article undergoes a different degree of shrinkage than another area or direction, the part will warp. During plastication, injection, packing, cooling and ejection processes, the residual stress is produced due to high pressure, temperature change, and relaxation of polymer chains, resulting in warpage of the part. In order to yield a product with high precision, optimum mold geometry and processing parameters must be found. The objectives of AD are to guide the designers, developers, and other members of a multi-disciplinary product development team throughout the development effort as well as to help managers capture and manage the knowledge produced by the development effort. The proposed model shall use the AD method to improve the quality of the preliminary design with the use of axioms in order to reduce the random searches for solutions, to minimize design iterations, and to easily integrate other design tools and methodologies with AD. The proposed model shall extend the AD method to cover the whole Product Design so that all of the domain entities are developed systematically and the relationships between the domain entities are identified and documented as well as any decisions made or assumptions used in developing the domain entities and their relationships. In this report, an attempt is made to apply an AD for "process planning" in injection molding process using DFSSV5.2 software. Modeling is done by using CATIA V5 software.

II LITERATURE SURVEY

In the past, David O. Kazmer et al. [1] discussed the application of axiomatic design principles to gain controllability of the injection molding process by considering dynamic temperature control enables temporal decoupling of the injection and solidification stages to increase the process performance. Nam Pyo Suh et al. 1983 [2] developed the Axiomatic Design process and he explained how to develop the axioms and design matrix for any system. Baldwin, D.F et al.[3] developed the micro cellular polymer processing it in a continuous sheet processing systems. Colton, T.S. & Nam Pyo Suh et al. [4] did work and they write a book on nucleation of micro cellular foams.

Du-Soon Choi, Yong-Taek Im et al. 1999 [5] in their study, the numerical analysis of shrinkage and warpage of injection molded parts made of amorphous polymers was carried out in consideration of the residual stresses produced during the packing and cooling stages of injection molding. The temperature and pressure fields were obtained from the coupled analysis of the filling and post-filling stages. For residual stress analysis, a thermo-rheologically simple visco-elastic material model was introduced to consider the stress relaxation effect and to describe the mechanical behavior according to the temperature change. The effect of the additional material supply during the packing stage was modeled by assigning the reference strain. The deformation of injection molded parts after ejection induced by the residual stress and temperature change was analyzed using a linear elastic three-dimensional finite element approach. In order to verify the numerical predictions obtained from the developed program, the simulation results were compared with the available experimental data in the literature. In the case of residual stress, it was found that the present simulation results over predicted the tensile residual stresses at the surface of injection molded parts. However, the predicted shrinkage was found to be reasonable to describe the effects of processing conditions well. Finally, an analysis of the shrinkage and warpage was successfully extended for a part with a more complex curved shape.

B. Ozcelik, T. Erzurumlu et al. 2006 [6] in their study, Plastic injection processes comprise plastication, injection, packing, cooling, ejection and process/part quality control applications. These steps are followed for the parts, which are designed to be produced by plastic injection method. Having initial knowledge about the process that will be undertaken is necessary because of present-day competitive conditions that force us to produce faster and cheaper with a higher quality, such as minimum warpage, sink marks, etc. Computer-aided analysis and engineering software's are used in order to meet this necessity. For plastic injection process, one of the commercial computer-aided engineering software's is the MoldFlow Plastic Insight. Best gate location, filling and flow, warpage applications have done for minimum warpage of plastic part with this tool. Process parameters such as mold temperature, melt temperature, packing pressure, packing time, cooling time, runner type and gate location are considered as model variables. The effects of process parameters for thin shell plastic part were exploited using both design of experiment (DOE), Taguchi orthogonal array and finite element software MoldFlow (FE). The most important process parameters influencing warpage are determined using finite element analysis results based on analysis of variance (ANOVA) method. Artificial neural network (ANN) is interfaced with an effective GA to find the minimum warpage value.

Ko-Ta Chiang et al. 2006 [7] they did their work on fast and effective methodology for the optimal process conditions of an injection-molded thermoplastic part with a thin shell feature based on the orthogonal array with the grey relational analysis and fuzzy logic. The proposed optimal procedure in solving the optimal multi-responses problem applies the grey relational coefficient for each machining response and converts a grey fuzzy reasoning grade to evaluate the multiple machining responses. One real case study in the injection molding process of Polycarbonate/ Acrylonitrile Butadiene Styrene (PC/ABS) cell phone shell has been performed to substantiate the proposed optimal procedure in order to indicate its feasibility and effectiveness. Through the grey-fuzzy logic analysis, the principle injection molding parameters, namely the opening mold cavity time, mold temperature, melt temperature, filling time, filling pressure, packing time, packing pressure and cooling time, are optimized with considerations of multiple machining responses including the strength of welding line, shrinkage and difference of forming distributive temperature. The results of confirmation test with the optimal levels of process parameters have obviously shown that the above machining responses in the injection molding process can be improved effectively together through this procedure. In addition, the analysis of variance (ANOVA) is utilized to find the effect of machining parameters on the multiple machining responses problem of the injection molding process.

Matsuoka et al. [8] developed an injection molding analysis program considering mold cooling and polymer filling–packing-cooling to predict warpage. Hastenberg et al. [9] measured the residual stress distributions in injection molded flat plated using a modified layer-removal method.

Jansen et al. [10] systematically studied the effect of processing conditions such as holding pressure, injection velocity, and mold and melt temperatures on shrinkage.

III PRODUCT DEVELOPMENT AND DESIGN METHODOLOGIES

There are a number of techniques and methods currently used in product design and development, such as, QFD, TRIZ, and robust design. The use of these and some other design and analysis techniques is very consistent with the Axiomatic Design (AD). The designer can follow the AD method and uses the various other techniques when appropriate. In fact, the structure and hierarchy generated through AD can help the designer apply these techniques easier and better. For example, the AD helps the designer avoid mistakes such as unknowingly attempting to optimize a coupled design. The other methods generally deal with a certain portion of the product development process such as requirement analysis, identifying a solution to a specified need, optimizing the proposed design, etc.

However, the AD method starts with a customer needs assessment and traces requirements and design decisions throughout the domains defined in the preceding section and the AD establishes the system architecture.

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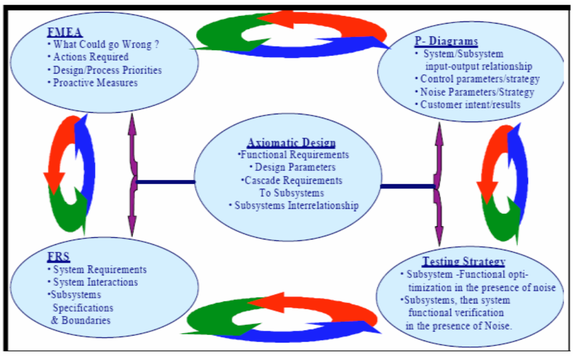

Fig 1: Product Development Cycle

There are four main concepts in axiomatic design:

a) domains

b) hierarchies

c) zigzagging

d) design axioms

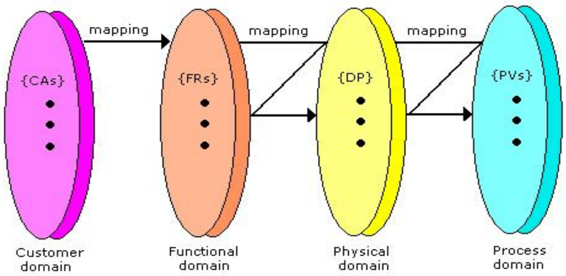

Fig 2: Axiomatic Design

IV EXPERIMENTAL DETAILS

Injection Molding is a net – shape process for the manufacturing of plastic products. It is a serial process that involves four stages: *plastication, injection, cooling, and ejection.* In plastication, plastic pellets are fed from a hopper into a heated barrel, where they are melted through the combination of heat supplied from a rotating screw (which causes viscous heating) within the barrel and heaters that lie around the outside of the barrel. As the screw rotate, material builds up in front of the screw until a specific volume is accumulated. This volume is the amount of plastic will be injected in one shot, and is commonly known as the shot size. Since the barrel has a constant cross – sectional area, the shot size is usually measured in inches of screw position.

At this point, the injection cylinder causes the screw to move forward via hydraulic pressure, injecting the plastic into the mould. The plastic flows from the barrel through a material delivery system to get to the gate, which is the entrance to the mould cavity. The material delivery system is compressed of runners that transfer the plastic from the nozzle to the gate. There are two types of runners: cold runners, which solidify upon filling and have to be ejected with the part: and hot runners, which are always full of molten plastic. Heaters are placed at various points along the path of the hot runner system in order to keep as the fill time. Manufacturing engineers commonly measure the screw position as a function of time and choose 98 or 99 percent of the full travel of the screw as the fill time.

As soon as the plastic enters the mold, cooling begins. As the plastic cools, it changes from a liquid to a solid and consequently shrinks. Shrinkage will be discussed in more detail in the following section. For that reason, moulders attempt to pack the plastic into the mold after it is initially filled. In general, the more plastic that is packed into the mold, the less the part will shrink. This process occurs at the end of the injection stage. The fill – to – pack switch – over occurs at the same 98 or 99 percent of the screw travel point. There are several other methods of fill – to – pack stage transfer, including time, in – cavity pressure, and parting line control: for more information.

When the gate freezes, the machine can no longer pack additional plastic into the mold, but additional cooling is usually necessary. Once the plastic has cooled to the point where it will not deform upon ejection, the mold opens and the parts are ejected from the mold into a bin. There are several techniques for ejecting parts, and the choice of ejectors usually depends on the part shape, among other factors. After ejection, the mold closes and the process repeats. The cycle time for injection moulding, therefore, is comprised of the fill time, the pack (or hold) time, the cooling time, and the mold – open time (this time refers to the time is taken for the mold to open, eject the part and close). Most cycle times range from a few seconds to a few minutes.

In order to achieve best moulding you need the right combination of the four factors. They are I) injection pressure II) Cylinder temperature III) Cycle time IV) Mould temperature.

4.1 Axiomatic Approach to Process Design

The Axiomatic design has been implemented for process design of injection moulding process by considering the process parameters such as mold temperature, melt temperature, packing pressure, packing time and cooling time. The simulation model of elbow plastic part is made in CATIA V5 SOFTWARE.

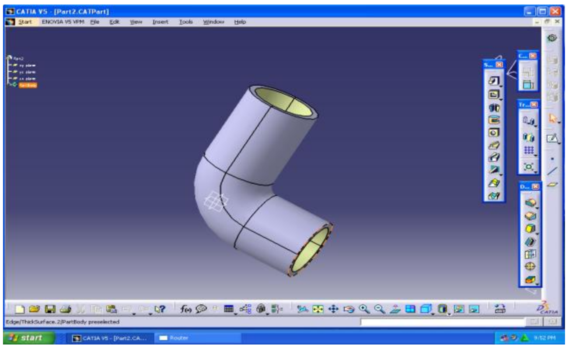

Fig 3: Elbow Plastic Part

4.2 Design Process

Consider the design of moulded part. The primary shape of an injection-moulded part is usually designed to satisfy a set of FRs, including the desired external appearance. The mould ability of the part and its mechanical performance are also considered separately based on the product design, while mold designing it must be provided. Supplementary features are then added to the primary shape by experienced mold engineers to

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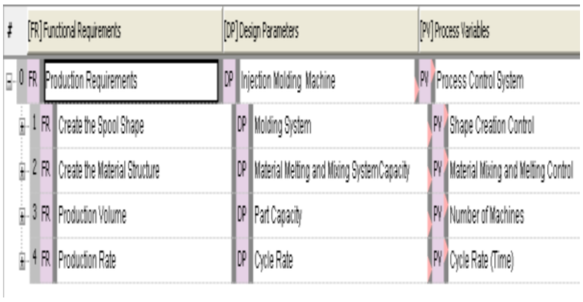
reinforce the structure, to facilitate the melt flow, and to supplement the FRs with additional FRs. The choice of the design of the machine control system, the settings on the control system, and the control limits of the settings, which comprise PV1 from the equation relating the design parameters to the process domain equation (1), the selection of PV3 affects the part shape, the polymer structure, and the machine:

[DP] = [M][PV] ……………………………..(1)

V RESULTS

Axiomatic Design method is used in the proposed model to improve quality of the preliminary design with the use of axioms in order to reduce the random searches for solutions, to minimize design iterations by using AcclaroDFSSV5.2, which is shown below

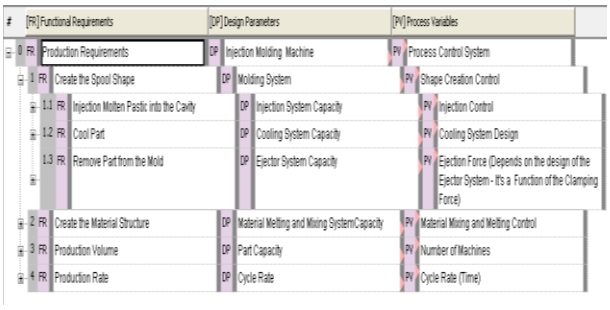
In this step we are representing highest level FR's, DP's, and PV's



#	[FR] Functional Requirements	[DP] Design Parameters	[PV] Process Variables
0	FR Production Requirements	DP Injection Molding Machine	PV Process Control System
1	FR Create the Spool Shape	DP Molding System	PV Shape Creation Control
2	FR Create the Material Structure	DP Material Melting and Mixing SystemCapacity	PV Material Mixing and Melting Control
3	FR Production Volume	DP Part Capacity	PV Number of Machines
4	FR Production Rate	DP Cycle Rate	PV Cycle Rate (Time)

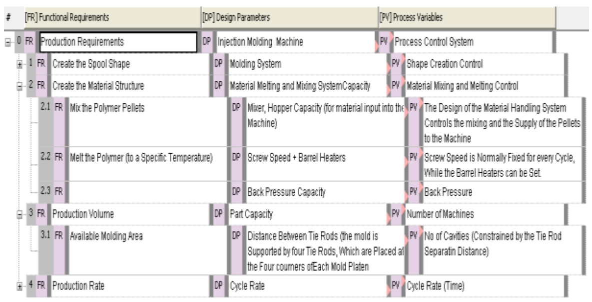
Fig 4: FR, DP Decomposition

In this step higher level FR's, DP's, PV's are decomposed layer by layer to ever lower levels until the design solution can be implemented. Through this decomposition process the designer establishes hierarchies of FR's, DP's, PV's.



#	[FR] Functional Requirements	[DP] Design Parameters	[PV] Process Variables
0	FR Production Requirements	DP Injection Molding Machine	PV Process Control System
1	FR Create the Spool Shape	DP Molding System	PV Shape Creation Control
1.1	FR Injection Molten Pastic into the Cavity	DP Injection System Capacity	PV Injection Control
1.2	FR Cool Part	DP Cooling System Capacity	PV Cooling System Design
1.3	FR Remove Part from the Mold	DP Ejector System Capacity	PV Ejection Force (Depends on the design of the Ejector System - It's a Function of the Clamping Force)
2	FR Create the Material Structure	DP Material Melting and Mixing SystemCapacity	PV Material Mixing and Melting Control
3	FR Production Volume	DP Part Capacity	PV Number of Machines
4	FR Production Rate	DP Cycle Rate	PV Cycle Rate (Time)

Fig 5: FR, DP Decomposition For 1st Link



#	[FR] Functional Requirements	[DP] Design Parameters	[PV] Process Variables
0	FR Production Requirements	DP Injection Molding Machine	PV Process Control System
1	FR Create the Spool Shape	DP Molding System	PV Shape Creation Control
2	FR Create the Material Structure	DP Material Melting and Mixing SystemCapacity	PV Material Mixing and Melting Control
2.1	FR Mix the Polymer Pellets	DP Mixer, Hopper Capacity (for material input into the Machine)	PV The Design of the Material Handling System Controls the mixing and the Supply of the Pellets to the Machine
2.2	FR Melt the Polymer (to a Specific Temperature)	DP Screw Speed + Barrel Heaters	PV Screw Speed is Normally Fixed for every Cycle, While the Barrel Heaters can be Set
2.3	FR	DP Back Pressure Capacity	PV Back Pressure
3	FR Production Volume	DP Part Capacity	PV Number of Machines
3.1	FR Available Molding Area	DP Distance Between Tie Rods (the mold is Supported by four Tie Rods, Which are Placed at the Four coumers ofEach Mold Platen	PV No of Cavities (Constrained by the Tie Rod Separatin Distance)
4	FR Production Rate	DP Cycle Rate	PV Cycle Rate (Time)

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Fig 6: FR, DP Decomposition For 2nd, 3rd Link

#	[FR] Functional Requirements	[DP] Design Parameters	[PV] Process Variables
0 FR	Production Requirements	DP Injection Molding Machine	PV Process Control System
1 FR	Create the Spool Shape	DP Molding System	PV Shape Creation Control
2 FR	Create the Material Structure	DP Material Melting and Mixing SystemCapacity	PV Material Mixing and Melting Control
3 FR	Production Volume	DP Part Capacity	PV Number of Machines
4 FR	Production Rate	DP Cycle Rate	PV Cycle Rate (Time)
4.1 FR	Plastication Rate (Blending is Usually Done Off-line)	DP Machine Plastication Rate (Mixing is Usually Dor Off-line)	PV Screw Recovery Time
4.2 FR	Injection Rate (Which Can be Decomposed into Filling and Packing Rates)	DP Injection System Rate (Usually the Machine has aLimit on this Rate Based on its Hydraulic Systems)	PV Injection Rate (through Velocity Control of the Screw Position)
4.3 FR	Cooling "Rate" (In this Case, the Cooling Rate is Constraint and the Required cooling Time can b Specified based on the Overall Cycle Time)	DP Mold Cooling System Rate (Limited by the Amou and Size of Coolant Channels that can be fit into the Mold and Palced Close to the Cavity)	PV Cool Time (Set on the Machine and Constrained by the Amount of Solidification is Required so tha the Part will not Deform upon Ejection)
4.4 FR	Mold Opening Rate (In General, this Stage Woul Include the Ejection Time)	DP Mold Opening Rate (the Ejectoer Rate is Only Limited by the Mechanical or Hydraulic Responc Time - Usually 0.2 Sec)	PV Mold Closed Time
4.5 FR	mold Closing Rate	DP Mold Closing Rate	PV

Fig 7: FR, DP Decomposition For 4th Link

This is the resultant design matrix for the functional requirements and design parameters which are stated above.Although the injection rate comprises only a small portion of the overall cycle rate, it dictates the ability of the machine to control the creation of the plastic into the mold (because it is the derivativeof the acceleration of the plastic). Unfortunately, the resistance of the plastic to injection, which is the polymer viscosity in the filling stage and the polymer compressibility in the packing stage, varies as the plastic flows through the runner system and into the mold. In addition, the properties of the material which dictate this resistance can vary, depending upon the mixing and melting system and the injection pressure to with in narrow limits. Since a consistannt volume flow rate of material into the mold cavities is desired (FR111), it is better to control the injection rate and let the injection forces vary according to the resistance to the material, this control method is known as velocitycontrol.

Now that the production requirements and machine parameters have been fully decomposed, the relationship between the process control systems are designed so that the operator can set up the machine to achieve the production requirements directly.

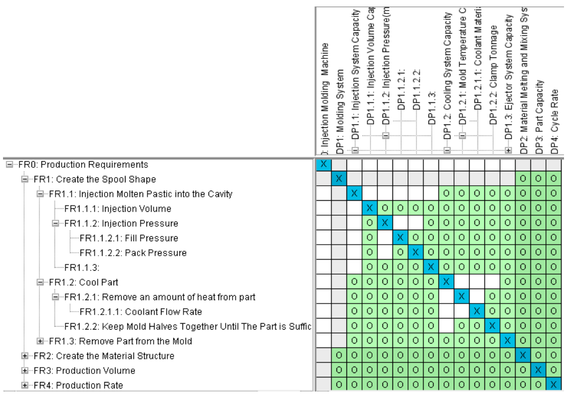

Fig 8: Design Matrix With 1st Level Expansion

In this case, the matrix is coupled, but in this case, the coupling of the cool time with the screw recovery time allows the new plastic tomelt sufficently without adding any time to the process. The first coloumn and row of the equation can then be eliminated from the monitoring (system although thevmovement of the screw must still becontrolled, the melting stage will not directly affect the cycle time). The remaining 4*4 matrix is decoupled,a logical result of asequential process.Having a complete mapping of FR's to DP's and of DP's to PV's, one can understand the interactions across the domines and assign criticality. However, sometimes one wishes to understand the nature of defect generation from process. In order to get a simple understanding of the this phenomenon, the completematrix formed by using Accelero DFSSV5 software

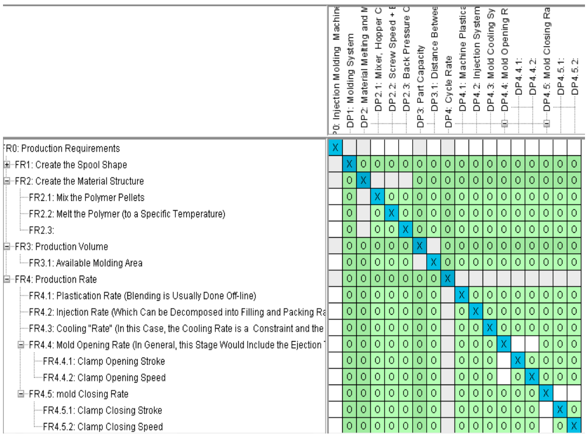

Fig 9: Design Matrix With 2nd, 3rd, 4th Level Expansion

By using AcclaroDFSSV5.2 we find out critical parameters that influence the performance of injection molding process.

VI CONCLUSIONS

The proposed methodology aims to provide general guidelines for the problems that are caused in injection moulding process using Axiomatic Design Acclaro DFSSV5 software.

1. Proper viscosity of the plastic obtained by varying the melt & mold temperatures which results complete filling of the mold.
2. Burns are avoided by increasing the inlet water cooling temperatures.
3. Warping is avoided by varying the ejector force and balancing of gates and runners.
4. Flashing is avoided by varying the clamping force.
5. Pore finish is avoided by increasing the injection pressure and mold temperature.

Bubbles in the finished part due to moisture content in the plastic material are eliminated by providing proper heating to the plastic material.

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