OPTIMAL DESIGN OF CANE INTER-CARRIER WITH APRON MECHANISM

Thesis submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF ENGINEERING IN MECHANICAL ENGINEERING

(INDUSTRIAL ENGINEERING)

of BHARATHIAR UNIVERSITY

By

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CHARACTER IS LIFE

DEPARTMENT OF MECHANICAL ENGINEERING

KUMARAGURU COLLEGE OF TECHNOLOGY

(Affiliated to Bharathiar University)

COIMBATORE – 641 006

1999 - 2000

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During the above period his conduct and character were found to be **GOOD**.

FOR SAKTHI SUGARS LTD.,

T. Venkt

DY.MANAGER/HRD.

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DEDICATED TO

MY

BELOVED PARENTS

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SYNOPSIS

Sakthi Sugars Limited, Sakthi Nagar having a crushing capacity of maximum 3500 tons crushed per day per each tandem mill, four crore tons of cane since from its inception from 1964 and produced three crore quintals of white sugar. Company is producing three grades of sugar crystals such as 400, 800 and 1200 μm sizes.

Cane is unloaded after weighing and fed to the cane preparative devices by the sling system to prepare the cane for crushing in the mills. The separation of juice from fibrous portion of cane is carried out by six adjacent mills. The crushed fiber Bagasse is conveyed to the next mill by INTER-CARRIER ARRANGEMENT. Imbibition system is used during crushing for better extraction of juice. Failure of inter-carrier arrangement is caused by wear and shear failures of chain link and slat. Failure disturbs the sugar production process by

1. Idling the process for repair or rework.
2. Effective Imbibition system cannot be achieved.
3. Frequent maintenance is necessary to avoid heavy damage to the other components.

The project " OPTIMAL DESIGN OF CANE INTER – CARRIER WITH APRON MECHANISM " focuses on to eliminate wear and shear failures and optimize the Design of Cane Inter - carrier Arrangement.

ABBREVIATIONS

TCD	→	Tons Crushed / day
TCH	→	Tons Crushed / Hour
μm	→	Micrometer
PCD	→	Pitch Circle Diameter
V_{min}	→	Minimum Velocity of Chain
V_{max}	→	Maximum Velocity of Chain
Rpm	→	Revolutions / Minute
Hp	→	Horse Power
Cm	→	Centimeter
mm	→	Millimeter
Kgf-m	→	Kilogram force – Meter
Kgf / m	→	Kilogram / Meter
Kg / min	→	Kilogram / Minute
Kg / sec	→	Kilogram / Second
tons / hour	→	Tons / Hour
lit / hour	→	Liters / Hour
m / min	→	Meter / Minute
C_j	→	Undetermined constants
ϕ_j	→	Trial functions

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INTRODUCTION

1. INTRODUCTION

1.1 Introduction about Company

Sakthi Sugars Limited, One of the Sakthi Group of companies was erected in the year 1964, by Dr. N. Mahalingam. It is one of the well-established Sugar producing industry. The company grew to the position of leadership in the field of sugar production by maintaining quality levels of standard sizes.

1.1.1 Plant Supplier

Walchand Nagar Industries Limited,
Walchand Nagar, Pune.

1.1.2 Crushing Capacities and Achievements

Capacity in 1964	:	1250 TCD
Capacity in 1967	:	1600 TCD
Capacity in 1971	:	2200 TCD
Capacity in 1974	:	4000 TCD
Capacity in 1998	:	6000 TCD
Capacity in 1999	:	6750 TCD
Achievements	:	Asia's Largest Sugar producing Industry.

1.2 Introduction to Design

Design is an iterative problem solving process. The iterative nature of design is owing to feedback from existing design and improvement with further information in the form of technological, financial and creativity inputs. Usually there is more than one solution to any problem, and the first one is not always the best. The choice of design concept must be optimal amongst the available alternatives; the selection of the chosen design concept must be optimal among all possible design proposals.

1.3 Introduction to Optimization

Optimal design means the best of all feasible designs proposed in one phase, i.e., the conceptual design. Optimization is the process of maximizing a desired quantity or minimizing the undesired quantity. Optimization theory is the body of mathematics that deals with the properties of maximal and minimal.

Siddal has reviewed the development of optimal design methods into the following classifications namely, optimization by evolution, optimization by intuition, optimization by trial and error modeling, optimization by numerical algorithm. Among these, Optimization by evolution is considered in this project. Optimization by evolution deals with relationship between technological evolution and biological evolution. Most designs in the past have been optimized by an attempt to improve on an existing design. Survival of the resulting variations depends on the natural selection of user acceptance.

1.4.1 Introduction to Finite Element Analysis

Virtually, every phenomenon in nature, whether biological, geological or mechanical, can be described with the aid of the laws of physics, in terms of algebraic differential or integral equations relating various quantities of interest. While the derivation of the governing equations for these problems is not unduly difficult, their solution by exact methods of analysis is a formidable task. In such cases approximate methods of analysis provide alternative means of finding solutions. Among these the Finite Difference methods and the Variational Methods such as Ritz and Galerkin methods are more frequently used in the literature.

In the Finite Difference approximation of a differential equation, the derivatives in the equations are replaced by differential quotients, which involve the values of the solution at discrete mesh points of the domain. The resulting discrete equations are solved after imposing Boundary conditions, for the values of the solution at the mesh points. Although the Finite Difference Method is simple in concept, It suffers from several disadvantages. The most notable are the inaccuracies of the derivatives of the approximated solution, the difficulty in imposing the boundary conditions along non-straight boundaries, the difficulty in accurately representing geometrically complex domains, and the inability to employ non-uniform and non-rectangular meshes.

In the Variational solution of differential equations, the differential equation is put into an equivalent Variational form and then the approximate solution is assumed to be a combination ($\sum C_j\phi_j$) of given approximation function ϕ_j. The parameter C_j is determined from Variational form. The Variational methods suffer from the disadvantage that the approximate functions for problems with arbitrary domains are difficult to construct.

1.5 Introduction to project

The separation of juice from fibrous portion of cane is done by milling crushers. The crushed fiber bagasse from one mill to its adjacent mill is carried by inter-carrier, which fails frequently due to wear and shear failure of the assemblies of link and slat.

Elimination or reduction of the above problems is possible by modifying the design of chain conveyor encompassing the following:

1. To modify the sprocket design in-order to reduce polygonal actions.
2. To modify the driving shaft sprocket design of the inter-carrier, in-order to maintain the speed of the inter-carrier.
3. To modify the link design in-order to reduce wears in the link.
4. To suggest remedies for the slat failures.

In this project, an attempt is made to optimize the design of link-slat type chain conveyor considering the strength of the conveying system. The design analysis is done using FINITE ELEMENT ANALYSIS.

OBJECTIVES &
PROBLEM DEFINITION

2.1 OBJECTIVES

The main objective of the project focuses on the failure analysis of cane inter-carrier and to overcome those failures with optimum cost and simple manufacturing process considering life time also into account. Failure of the inter-carrier affects the continuous running process by

- Stoppage of the process for repair or rework.
- Frequent maintenance is necessary.

The remedies should posses the following flexibilities:

- Design should be simple with less investment.
- Parts should be ease in production.
- Life of the components should be increased than existing one.
- Components should resist wear, vibrations and impact loads.
- Components should be able to operate under the assigned duty without any damage.
- Parts must be much smoother and quieter in action during motion or mating with other parts.
- Parts must be sufficiently strong and rigid.
- Efficiency of the components should be improved than the existing one.
- Design should eliminate frequent maintenance.
- Components should with stand corrosive effect of the juice.
- Components should with stand abrasive effect and expected operating speed.

2.2 PROBLEM DEFINITION

2.2.1 Cane Preparation

The harvested cane received in factory is weighed in the weighbridge, unloaded and fed to the cane preparative devices by the "SLING SYSTEM". Cane is carried to the leveler through the kicker, which controls the amount of cane passing to the leveler. Kicker rotates in opposite direction to which the cane is carried. The leveler checks the height of the cane and cuts the cane into pieces (2.5 – 5 cms). This cane is then passed through cutters that consist of numbers of hammer cum knife headed shaft, where 75-80% of cane is fibrized as shown in the Figure 1. Fibrized cane is carried to the milling section through Donnelley chute and 45° inclined Rake elevator.

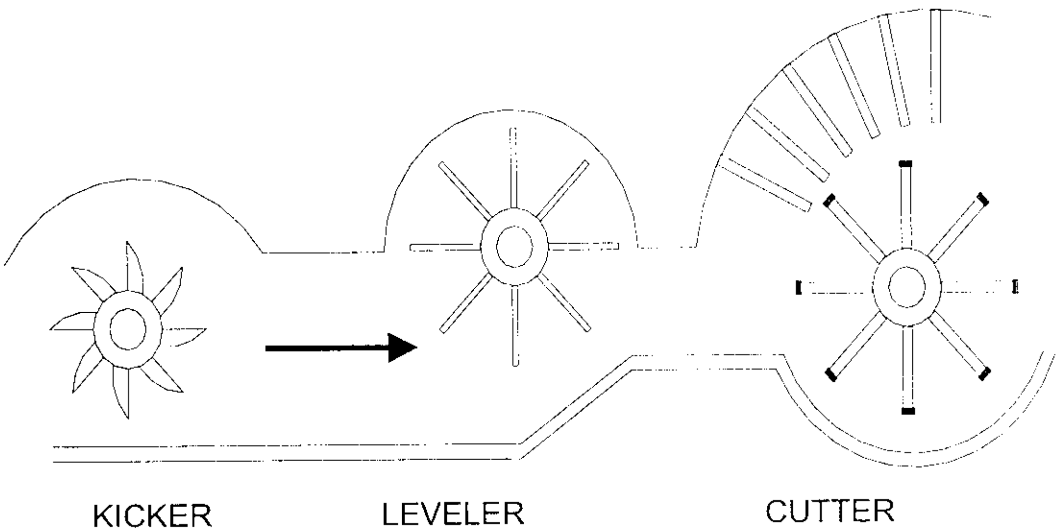

Fig. 1 CANE PREPARATIVE DEVICES

2.2.2 Mill Section

Each tandem mill consists of six milling units through which juice is extracted. Every mill has top roller, feed roller, discharge roller and Tooth roller pressed feeder for juice extraction. Trash plate in the bottom sides in-between the feed and the discharge rollers prevent the falling of cane in-between the rollers. The feed and discharge rollers are adjusted by means of hydraulically operated rams on both sides as shown in Figure 2.

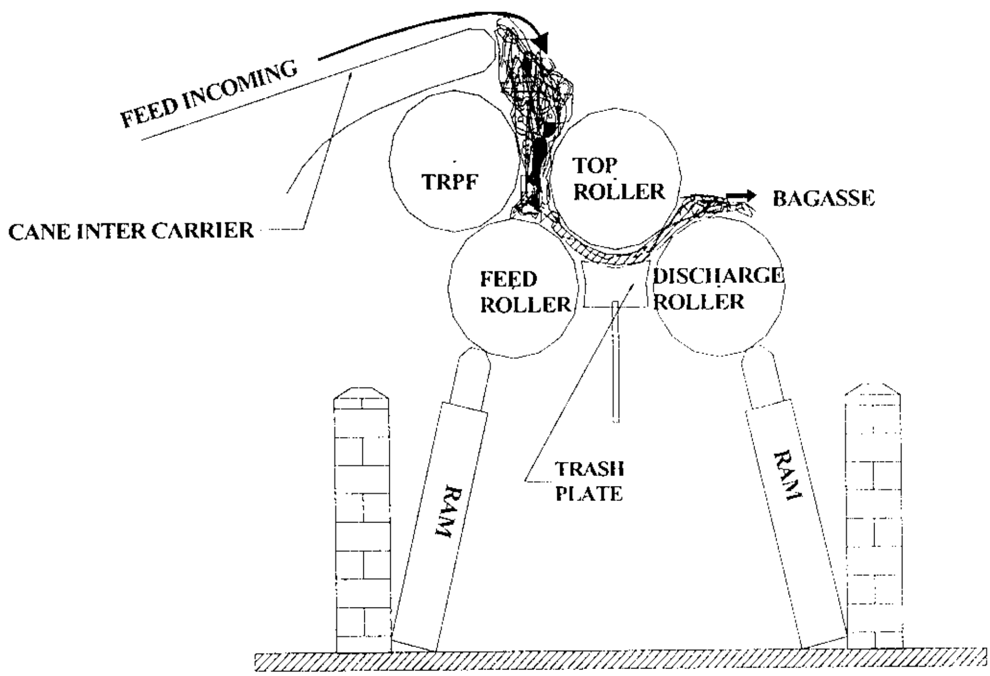

Fig. 2 MILL ARRANGEMENT

Compound Imbibition system i.e. addition of water in the last mill and diluted juice of the remaining mills are pumped to their respective previous mills for better extraction of juice. After extraction of juice in the sixth mill, the fiber bagasse is fed into boiler for power generation using steam turbine for running their accessories. The primary juice is pumped through the filter and strained juice is sent to process as shown in Figure 3.

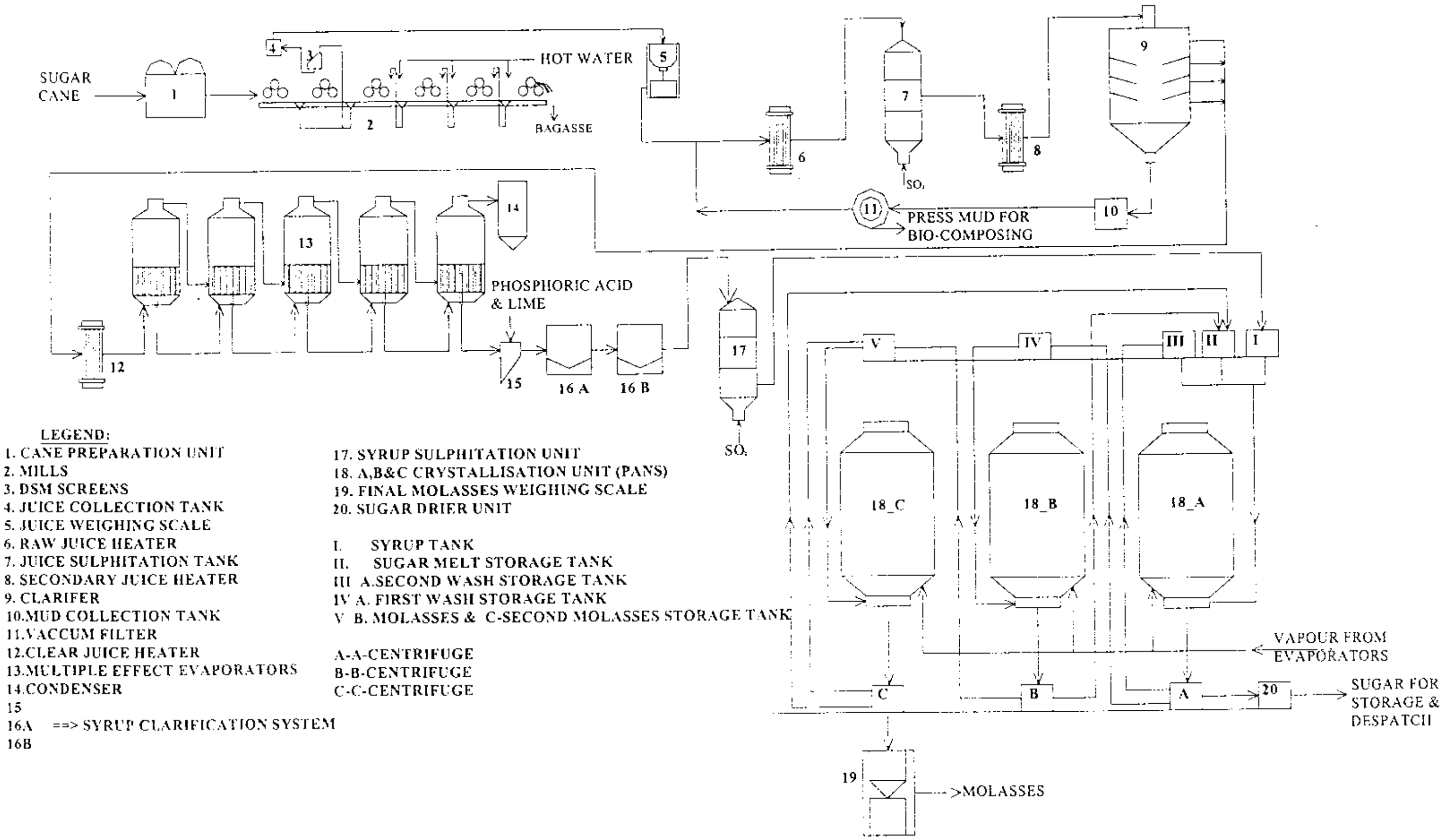

Fig. 3 SCHEMATICS OF SUGAR PRODUCTION FROM SUGAR CANE AT M/s SAKTHI SUGARS LTD.

2.2.3 Inter-Carrier Arrangement

Pintle type combination chain with steel slats conveyor is used to carry fiber bagasse from one mill to the next mill. There are seventy steel slats and two hundred and ten chain links in each inter-carrier. The carrier speed ranges from 15-20 m/min. and is driven by six sprockets at each end of loading and unloading stations.

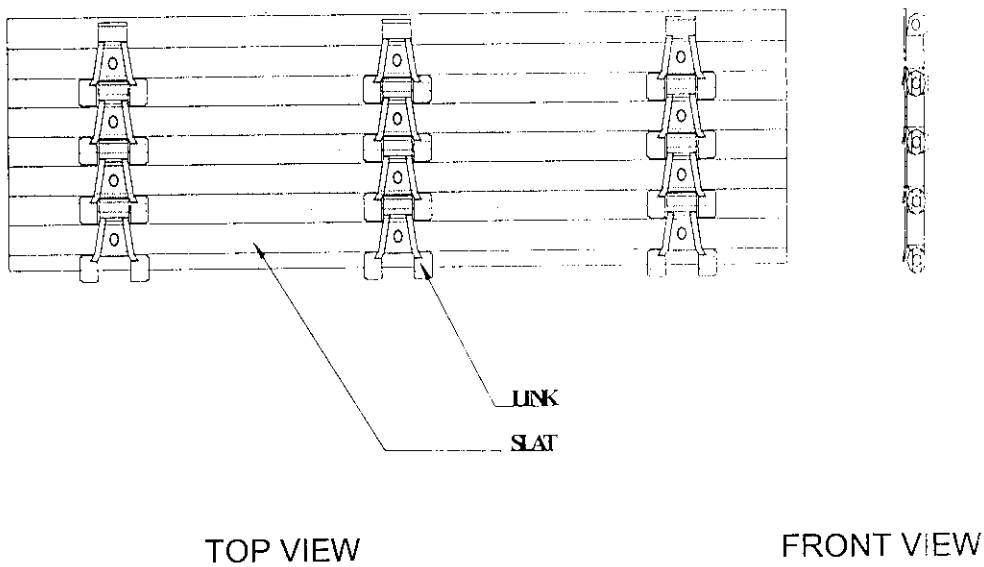

Fig. 4 LINK SLAT ASSEMBLY

Failure of the inter-carrier leads to

1. Break down of the process to repair or rework.
2. Effective Imbibition system cannot be achieved.
3. Repetitive maintenance is necessary.

The project focuses on the remedies for the failure of inter-carrier arrangement.

2.3 LITERATURE SURVEY

2.3.1 Introduction

Sugar factory is one of the continuous running process industries to produce white sugar. The stoppage of the process for a second will produce loss for the company to great extends. So unnecessary stoppage should be minimized for the profitable running of the company.

Preliminary approach to the problem was conducting a detailed analysis of the breakdown of the whole process in the sugar production. Then frequencies of each failed component are analyzed. Then maximum failing components are considered for the optimization in-order to avoid the stoppage of the process. One such problem has been taken into account to optimize the cane inter-carrier arrangement due to its excess impact on the process.

2.3.2 Stoppage Analysis

Stoppage analysis is a technique, which means that analyzing the causes for the stoppage of the process and the factors that cause the stoppage. This analysis will help to identify the problems that are caused by the failures of component present in all the equipments available. The causes for the stoppage of the process may be due to some of the following reasons:

- Failure of the parts due to wears, weak in strength, shock loads etc.
- Periodical Cleaning works.
- Periodical Maintenance works.
- Replacement of worn out parts etc.

2.3.3 Chain Conveyors – An Over View

Conveyor chains are classified according to the method of attachment of chain links. They are

1. **Detachable or hook joint type chain conveyor**

As the name indicates the chain is readily detachable for a replacement of links. The clearance between outer plates of a link is wider than the thickness of the inner plate in the adjacent link so that the links can be pivot with respect to each other through 7° in the plane of articulation. This feature provides for bending of the conveyor path at right angles referred to as drum bend corner.

2. **Closed end Pintle type chain conveyor**

Most of the installations are equipped with long-pitched rivetless chains. In these chains, a bushing interconnects two inner plates of one link, which are linked with adjacent link consisting of two outer plates secured by means of a pin secured to the plates and passing through the bushing to provide low unit pressure at the articulation. Bushings are commonly fitted with rollers of various configurations riding along guides and providing support for the conveyor and the load is moved. The most stressed and wearing-out parts of a chain are its pins.

(a) Slat conveyor

In these conveyors, steel or wooden slats are used to convey the materials. The slat conveyor consists of one or more chains to which platforms or slats are attached to carry load. The slats can be flat topped or of special design to support materials of odd shapes. The platforms or slats are not necessarily a part of each link. They can be located on every other link or at even greater distance apart.

(b) Steel plate conveyor

These conveyors are known as interlocking, overlapping or double-beaded types. The interlocking edges of the plates creates the continuous surface makes them particularly suitable for conveying bulky, loose materials.

The raised portion of their surface gives a corrugated effect, which prevents such materials from backsliding. Overlapping steel edges prevent materials from falling off the sides.

(c) Apron conveyor

The apron conveyor essentially consist of an endless belt of overlapping or interlocking metal plates or timber boards (platforms) connected by means of two or more strands of chain or by a slide running on tracks. The chains are bent over the tail and head sprockets and supported in-between suitably. The head sprocket shaft is generally driven and the tail sprocket shaft is provided with adjustment of pre-tensioning.

(d) Enmasse conveyor

The equipment is composed of an endless chain carrying a series of flights, at pitched intervals, the whole arrangement moving through enclosed duct. The flights, which may be in skeletal or solid form, slide along the metal duct and propel the mass of the material along its path. The duct can go around bends and follow slopes when changing plane and can be designed to follow either horizontal or vertical paths.

(e) Drag chain type conveyor

Here the chain supports the load on bare link or moves it by means of attachments such as lugs and trolleys. The trough consists of two parts one containing the carrying run and the other, the return run. In the carrying run, the material filling the cross sectional area completely is pushed through the trough by skeleton chain-attached flights at a speed lesser than that of the chain.

(f) Escalators type conveyor

It consists of stepped apron with two hauling chains, a drive, take-up, supporting metal structure with guide tracks, entry stages, an enclosure with frame, hand rails, reduction units, brakes and couplings. It is supplemented by a stand still drive used during inspection and repairs, which is geared either to motor shaft extension at the end opposite to the reducer or to the reducer input shaft.

(g) Flight or scraper conveyor

It consist of one or two endless chains fitted at regular intervals with flights which scrape forward the material in a trough which may be open or enclosed and discharge through gates in the bottom of the trough. The trough is faced with wood, steel or concrete and can be of various cross sections. Flights are made of steel or malleable iron plate. The chains may be of bush type or roller type or round link type. This conveyor moves the material batch-wise. These conveyors are likely to break the load in the coarse of transportation and are therefore used to handle unbreakable materials or those, which are not degraded due to breakage.

(h) Car type conveyor

These are arranged for operation in horizontal and moderately inclined planes to handle contained loose material and piece loads. Car inter-connected by propelling chains travel on wheels or rollers along rails. Car tops can be equipped with free turning rolls to minimize spillage of load and provide for the continuity of the bed on car turns. Guide rollers travelling along the guide track may replace wheels of the flanged type, characterized by high resistance.

(i) Pan type conveyor

Pan conveyors are a form of apron conveyors designed to handle sharp, highly abrasive or hot materials, machine parts and similar products. It consists of carrying surface commonly referred to as steel belting, piano-hinged belt or hinged steel belting. The pans are made from heavy-gauge steel formed to interlock on a belt pin mounted between two standard steel roller side chains.

In these types the existing design is Pintle type steel slat conveyor since for carrying the bagasse and to withstand the corrosiveness of the juice this type of conveyor is more suitable.

2.3.4 Design Optimization

2.3.4.1 What is Design Optimization?

It is a technique that seeks to determine an optimum design. By optimum design, we mean one that meets all specified requirements but with a minimum expense of certain factors such as weight, surface area, volume, stress, cost, etc. in other words, the optimum design is usually one that is as effective as possible.

Virtually any aspect of design can be optimized (such as thickness), shape (such as fillet radius), placement of supports, cost of fabrication, natural frequency, material property and so on. The optimized design should give flexibility in manufacturing that design easily at less investment.

2.3.4.2 Evolution of Design

Like many expressions in English language, the term " Engineering Design" has undergone a significant metamorphosis during the past twenty years. For the Engineering graduate of 1960's the term "Design" conjured up visions of long hours at a draftable table using the tools of a draftsman in the process of making drawings, a task not often sought after by most graduates.

Most new Engineering graduates invariably select analysis in preference to the design. The idea of working in the 'board' was considered to be undesirable because it was thought to be a young Engineer and not likely to lead to job growth. In actuality the situation was just reverse, the design engineering position was key and the analyst provided support, as required.

2.3.4.3 Evolution of optimization

Several mathematical techniques of optimization have been developed since 1950 and they have been gradually implemented to a variety of engineering design situations. The concurrent development of the digital computers, with their inherent capabilities for numerical calculations and search, has made the utilization of optimization procedures practical, in many design situations.

The optimization can be done in number of ways. One cannot predict the exact optimized solution since every problem has many optimal solutions. But optimization is the process of finding the best optimal solution to the problem. Optimality must be established relative to a design criterion, which represents the designer's compromise among possibly conflicting value judgements which include those of the consumer, the producer, the distributor and his own.

2.3.4.4 Design Optimization - an over-view

Problems associated with optimum design have been the subject of considerable attention for a number of years. During the last several decades the field of optimum design has made remarkable progress in systems design, control of dynamics, and Engineering Analysis. With recent advances in the field of Computer Technology, many modern Optimization methods have been developed and designing complex systems with the optimum configuration has become possible within a reasonable computation time. There are two kinds of effects inherently associated with any mechanical element or system. They are

1. Desirable effects such as long useful life, efficient energy output, good power transmission capability and high cooling capacity.
2. Undesirable effects such as high cost, excessive weight, large deflections and vibrations.

Optimum design can be defined as the best possible design from the most significant effects, that is minimizing the most significant undesirable effects and or maximizing the most significant desirable effects.

2.3.4.5 Methods of optimization

The mathematical methods for optimum design can be divided into two categories.

1. **Analytical methods**

This method includes differentiation, Variational methods, and the use of LaGrange multipliers.

2. **Numerical methods**

This method includes linear (Simplex method) and Non-linear programming methods such as One Dimensional minimization methods, Multi-variable Unconstrained methods, Multi-variable Constrained methods, Geometric methods, Dynamic programming, Stochastic programming, Theory of Games, Optimal control Theory, Combinational Methods such as Branch and Bound, Back Track methods.

Analytical method of optimization is used to solve the problem of failure of inter-carrier due to its heavy wear and shock loads acting in the conveyor.

2.3.4.6 Application of Optimization in Engineering Fields

1. Design of aircraft and aerospace structures for minimum weight.
2. Finding the optimal trajectories of space vehicles.
3. Design of civil engineering structures for minimum weight.
4. Controlling the waiting and idle times and queuing in production lines to reduce costs.
5. Optimal production planning and control.
6. Optimum design of electrical network.
7. Minimum weight design of structures for earthquake, wind and other types of loading.
8. Design of water resources system for maximum benefit.
9. Optimal plastic design of structures.
10. Design of pumps, turbines and heat transfer equipment for maximum efficiency.
11. Optimum design of electrical networks.
12. Optimum design of control systems.
13. Optimal design of chemical processing equipment and plants.
14. Design of optimum pipeline networks for process industries.
15. Selection of site for an industry.

2.3.5 Finite Element Analysis

2.3.5.1 What is Finite Element Method?

In the formulation of any design project, some sort of analysis is required. The analysis may be stress-strain calculations, heat transfer computations or the use of differential equations to describe the dynamic behavior of the system being designed. The computer can be used to assist in this work. Probably the most powerful analysis feature of a Computer Aided Design (CAD) system is the finite element method (FEM).

The FINITE ELEMENT METHOD was developed more by Engineers using physical insight than mathematicians using abstract methods. It was first applied to the problems of stress analysis and has since been applied to other problems of continua. In all applications the analyst seeks to calculate a 'field quantity'. In stress analysis, it is the displacement field or the stress field. The FEM is a way of getting a numerical solution to a specific problem. FEA does not produce a formula as a solution, but the solution is approximate unless the problem is so simple that a convenient exact formula is already available. The power of FEM is its versatility.

The structure analyzed may have arbitrary shape, arbitrary supports and arbitrary loads. An unsophisticated description of FEM is that it involves cutting a structure into several elements (pieces of structure), describing the behavior of each element in the simple way, then reconnecting elements at "nodes" as if nodes were pins or drops of glue that hold elements together. This process results in set of simultaneous algebric equations. In stress analysis, these equations are equilibrium equations of the nodes. There may be several hundreds or thousands of such equations, which means that computer implementation is mandatory.

2.3.5.2 Evolution of Finite Element Method

The idea of representing a given domain as a collection of discrete elements is not novel with the FEM. It was recorded that ancient mathematicians estimated the value of π by noting that perimeter of a polygon inscribed in a circle approximates the circumference of a circle. They predicted the value of π to accuracies of almost forty significant digits by representing the circle as a finitely large number of sides.

In modern times the idea found a home in aircraft structural analysis for e.g. wings and fuselages are treated as assemblages of stringes, skins and control panels. In 1941, Hrenikoff introduced the so-called framework method, in which a panel elastic medium was represented as a collection of bars and beams.

The use of piecewise continuous functions defined over a sub-domain to approximate the unknown function datas back to the work of Courant (1943), who used an assemblage of triangular elements and the principle of minimum potential energy to study the Saint Venant Torsion problem. Although certain key features of the FEM can be found in the works of Hrenikoff (1941) and Courant (1943), the formal presentation of the FEM is attributed to Arygyris and Kelsey (1960) and to Turnes, Clough, Martin and Topp (1956). However, the term "Finite Element" was first used by Clough (1960). Since its inception, the literature on finite element applications has grown exponentially.

2.3.5.3 Stages of Finite Element Method

The theory of FE includes matrix manipulation, numerical integration, equation solving and other procedures carried out automatically by commercial softwares. There are number of software packages available such as ANSYS, NISA, NASTRAN, PRO MECHANICA, IDEAS. These softwares contains three stages of solving the problems namely PRE-PROCESSOR, SOLUTION, POST-PROCESSOR stages.

In pre-processor stage, the modeling of the problem is to done. Modeling is the simulation of a physical structure or physical process by means of substitute analytical or numerical constructions. Modeling requires the physical action of the problem be understood well enough to choose suitable kinds of elements and to represent the physical action adequately.

In solution stage, the boundary conditions and constraints are given to the physical model including the loads acting on the structure. The loads may be applied on the structure at a point or area or volume. The flexibility in the solution stage is that applied load parameters are distributed to the whole domain by the element connectivity. Here the matrix manipulations and numerical integrations are done, by using different types of solvers like Frontal solver.

In post-processing stage, the results are taken such as stress, strain, deformation and strength etc. The post processing involves plotting the dynamic behavior of the structure in terms of graphics, graphs, and contours. etc. The values of stresses, deformations can be exactly predicted.

1.4.2 Flexibilities in Finite Element Method (FEM)

The FEM overcomes the difficulty of the Variational Methods because it provides a systematic procedure for the derivation of the approximate functions. The method is endowed with two basic features, which account for its superiority over other competing methods.

First, a geometrically complex domain of the problem is represented as a collection of geometrically simple sub-domains, called Finite Elements. Second, over each finite element the approximate functions are derived using the basic idea that any continuous function can be represented by a linear combination of algebraic polynomials.

The approximation functions are derived using concept of interpolation theory, and are therefore called interpolation functions. Thus, the finite element method can be interpreted as a piecewise application of the Variational Methods (e.g. Ritz and Weighted Residual Method) in which approximate functions are algebraic polynomials.

The undetermined parameters represent the values of the solution at a finite number of pre-selected points, called nodes, on the boundary and in the interior of the element. From the interpolation theory one finds that the order or degree of the interpolation function depends on the number of nodes in the element.

2.4 PROBLEM IDENTIFICATION

The bagasse is carried to the next mill by means of inter-carrier, which fails due to wear and shear in the chain and link of the conveyor assembly. The causes for the failures are analyzed and identified. Some of them are

- **Polygonal action of the chain when it meshes with the sprockets.**

When chain passes over the sprocket, it moves as a series of chords, instead of a continuous arc as in the case of belt drive. Thus the centerline of the chain is not moving at a uniform radius. Irregularities in the motion of the chain are responsible for dynamic stresses. High pitch of the chain with small PCD and less number of sprocket teeth induces the polygonal action.

- **Non-uniformity of linear speed of the carrier.**

When the driving sprocket moves at a constant speed, the driven chain rotates at a varying speed due to continually varying radius of the chain line. As a result the sprockets of the chain drive do not have a constant angular velocity ratio and therefore the linear velocity of the chain is irregular.

- **Hinged portion of the slat gets weakened due to wear and corrosive effect of juice.**

When the slat is carrying Bagasse, the hinged portions are getting worn due to impact load during continuous loading and unloading areas due to the polygonal action of the chain. As the portion gets weakened the crack propagates from the center and results in the failure.

2.5 SOFTWARES USED IN THE PROJECT

2.5.1 PRO/Engineer of version 2000i

This is excellent modeling software developed by PARAMETRIC TECHNOLOGY CORPERATION in the year 1999. The modeling of the components is the simulation of the exact physical system in to a model, which is used for analysis, image processing and documentation etc. This software is more flexible to model any puzzling component.

This software incorporates the following types of modules.

- Sketch
- Part
- Assembly
- Manufacture
- Drawing

This software also contains the following sub-types of the modules.

- Solid
- Composites
- Sheet metal.

Here the three dimensional part solid model has to be created in-order to encompass the volumetric feature in the part drawing. The part drawing can be created using some of the commands such as

- Protrusion
- Cut
- Chamfer
- Extrude

The protrusion of the parts can be done by using the following commands:

- Blend
- Sweep
- Revolve

The model of the parts can be created in the part mode in-order to encompass the volumetric feature in the model.

2.5.2 ANSYS of Version 5.6

This is excellent analysis software developed by ANSYS Inclusion Software Corporation in the year 1999.

About Graphic User Interface (GUI)

MAIN MENU

It contains the primary ANSYS functions, organized by processors (Pre processor, Solution, General post-processor, design optimizer etc.)

UTILITY MENU

It contains utility functions that are available throughout the ANSYS session, such as file controls, selecting, graphics controls, and parameters and Exit of ANSYS.

TOOL BAR

It contains push buttons that execute commonly used ANSYS commands and function. We can add our own push buttons by defining abbreviations.

INPUT WINDOW

It shows the program prompt messages and allows to type in commands directly. All previously typed in commands also appear for easy reference and access.

GRAPHICS WINDOW

A window where graphics displays is drawn.

OUTPUT WINDOW

It receives text output from the program. It is usually positioned behind the other windows and can be raised to the front when necessary.

METHODOLOGY

3. METHODOLOGY

1. Reduction of Polygonal Action

- The polygonal action causes irregularities in the speed of the chain. This variation in speed ranges from

$$V_{min} = 2\Pi NR \cdot \frac{180}{n_1} \quad \text{to} \quad V_{max} = 2\Pi NR$$

Where R = pitch radius of the sprocket, mm,

N = speed of driving sprocket, RPM,

n_1 = number of teeth on driving sprocket.

From the above equation, for the same pitch the variation decreases when the number of teeth in sprocket is increased. So by increasing the number of teeth we can reduce the variation.

FOUR TEETH SPROCKET FIVE TEETH SPROCKET

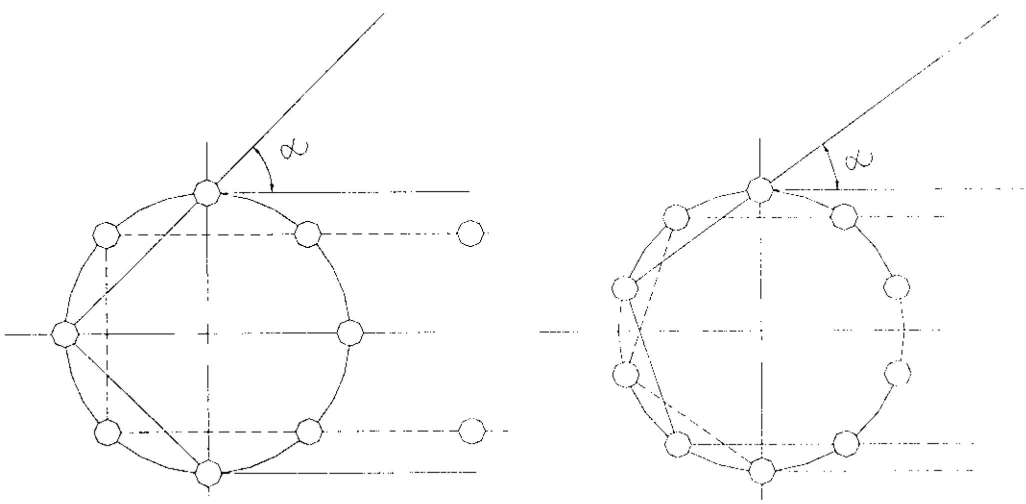

Fig. 5 CHORDAL ACTION OF CHAIN DRIVE

From the figure 5, the angle of articulation α decreases, as the sprocket teeth are increased. Since the rate of wear of chain pins and bushings are proportional to the angle of articulation, the greater the number of sprocket teeth will result in less wear and longer life of the chain i.e. the pinion should have seventeen or more teeth. It has been found that if the number of teeth is twenty-five or more the chordal action is negligible.

2. Reduction of Shear Failures of Link and Slat

These failures occur due to deficiency in strength, rigidity, reliability, material property, efficiency etc. The failure can be analyzed using Finite Element Analysis and design optimization can be done in-order to reduce failures. Accuracy of predicting the results in FEA helps to solve many engineering problems.

Many softwares are there to solve the equations and to iterate the solution. Using those softwares, the strength and stresses or dynamic behavior of the problems can be solved in no time. One such software named ANSYS is used in this failure analysis problem.

The model of the components are done in PRO/Engineer due to its extensive capabilities in three-dimensional modeling and imported for analysis. Then the link is analyzed and the design is modified and set to analysis and then the results are compared with the existing design. Then the slat is analyzed, stresses and deflections are compared with safety limit and found that value of shear stress is slightly greater than the safety limit. So to reduce the wear in the slat, suitable suggestions such as surface hardening (for increasing the shear strength) is given.

4 DESIGN DETAILS

4.1 Design of Sprocket

Increasing two teeth in the sprocket can reduce the variation of speed. The variation will reduce from 3% to 1.5% or less when sprocket teeth are increased from fifteen to seventeen numbers. The design is as follows:

1. Pitch circle diameter of the sprocket $= \dfrac{P}{\sin\left(\dfrac{180}{Z}\right)}$

$$D_0 = \frac{80.5}{\sin\left(\frac{180}{17}\right)}$$

$= 438$ mm.

$= 43.8$ cm.

2. Clearance between the fillet radius $= 0.04 \times Z \times \sqrt[3]{Q}$

where Q = ultimate tensile strength of chain kgf

= 11300 kgf.

$\therefore \quad e = 0.04 \times 17 \times \sqrt[3]{11300}$

$= 15.25$ mm.

3. Fillet radius $(r) = 0.5 \times d_1$

where d_1 = diameter of the bush

$= 37$ mm.

$\therefore \quad r = 0.5 \times 37$

$= 18.5$ mm.

4. Chamfer radius $R = P - (e + r)$

$= 8.05 - (1.525 + 1.85)$

$= 46.75$ mm.

5. Base diameter $= D_0 - 0.2 \times P$

$D_R = 43.8 - 0.2 \times 8.05$

$= 42.19$ cm.

6. Out side diameter $= D_0 + 0.5 d_1 + 6$ mm

$D_e = 44.64$ cm.

7. Bottom diameter $= D_0 - d_1$

$D_b = 43.8 - 3.7$

$= 40.1$ cm.

8. Maximum tooth thickness $= 0.9\, C_1$

where $C_1 =$ Distance between fillet radius and edge of the hub chain link.

$\therefore$ $b_1 = 0.9 \times 24$

$= 21.6$ mm

≈ 22 mm.

9. Tip thickness $b_2 = 0.83\, b_1$

$= 0.83 \times 21.6$

$= 17.93$ mm

≈ 18 mm.

4.2 Design of Driving Sprocket of Inter-carrier Shaft

To maintain the speed of the inter-carrier, the number of teeth in the driving sprocket of the inter-carrier should be changed. The design of the sprocket is as follows.

1. Speed of the driven sprocket $= N = \frac{\text{Velocity of chain}}{\Pi D}$

$$= \frac{15.42}{\Pi \times 0.438}$$

$$= 11.20 \text{ rpm.}$$

2. No. of teeth in the driving sprocket of inter - carrier $T_2 = T_1 \times \frac{N_1}{N_2}$

$$= 14 \times \frac{13.66}{11.20}$$

$$= 17 \text{ nos.}$$

3. Pitch of the driving sprocket of inter – carrier $P = 2''$

$$= 4.5 \text{ cm.}$$

4. Pitch circle diameter $= \frac{P}{\sin\left(\frac{180}{T_2}\right)}$

$$= \frac{4.5}{\sin\left(\frac{180}{17}\right)}$$

$$= 24.5 \text{ cm}$$

4.3 Design Modification of Slat

Loads acting in slat can be calculated from the ratio of amount of fibers present in cane, amount of fibers present in Bagasse and amount of juice or water added during the Imbibition system. The load details are as follows:

4.3.1 Load due to Bagasse weight

Fiber % Cane : 12.5 to 14%

Fiber % Bagasse :

Mill	I	II	III	IV	V	VI
Percentage	33%	42%	45%	47%	50%	52%

Sucrose : 1.9 %

Moisture : 50 %

For first mill,

$$\frac{\text{Fiber \% Cane}}{\text{Fiber \% Bagasse}} = \frac{13.5}{33} \times 100$$

$$= 40.9\ \%$$

$$\therefore \text{Bagasse \% cane} = 40.9\ \%$$

$$\text{Cane crushed / day} = 3500\ \text{TCD}$$

$$= 145.8\ \text{TCH}$$

$$\text{Load due to Bagasse weight} = 145.8 \times \frac{40.91}{100}$$

$$= 994.34\ \text{kg/min}$$

For second mill,

$$\frac{\text{Fiber \% Cane}}{\text{Fiber \% Bagasse}} = \frac{13.5}{42} \times 100$$

$$= 32.14\ \%$$

For third mill,

$$\frac{\text{Fiber \% Cane}}{\text{Fiber \% Bagasse}} = \frac{13.5}{45} \times 100$$

$$= 30\ \%$$

For fourth mill,

$$\frac{\text{Fiber \% Cane}}{\text{Fiber \% Bagasse}} = \frac{13.5}{47} \times 100$$

$$= 28.72\ \%$$

For fifth mill,

$$\frac{\text{Fiber \% Cane}}{\text{Fiber \% Bagasse}} = \frac{13.5}{50} \times 100$$

$$= 27\ \%$$

For sixth mill,

$$\frac{\text{Fiber \% Cane}}{\text{Fiber \% Bagasse}} = \frac{13.5}{52} \times 100$$

$$= 25.96\ \%$$

$\therefore$ Maximum % of Bagasse is discharged in the first mill.

So load calculations are done in the inter – carrier of that mill.

4.3.2 Load due to Imbibition System

For the Mills I – V,

Quantity of juice added = 20 lit/sec.

Density of the juice = 1.06 tons/m^3

$$\therefore \quad \text{Load} = \frac{20}{1000} \times 1.06$$

$$= 21.2 \ \text{kg/sec}$$

$$= 1272 \ \text{kg/min}$$

For Mill VI,

Quantity of water added = 35% of cane

$$= \frac{35}{100} \times 145.8$$

$$= 51.04 \ \text{tons/hr}$$

$$= 850.67 \ \text{kg/min}$$

4.3.3 Speed of the Apron Inter-Carrier

The output of the turbine power is given to the speed reducer in-order to reduce the speed and then to the secondary gear box where the speeds are controlled and then transmitted to the top mill roller. From the top roller the power is transmitted to the inter-carrier shaft through the clutch shaft. The function of the clutch shaft is to engage or disengage the power transmitting to the inter-carrier, when ever necessary.

Output speed of the turbine = 5000 rpm (Theoretical)

= 4400 rpm (Actual)

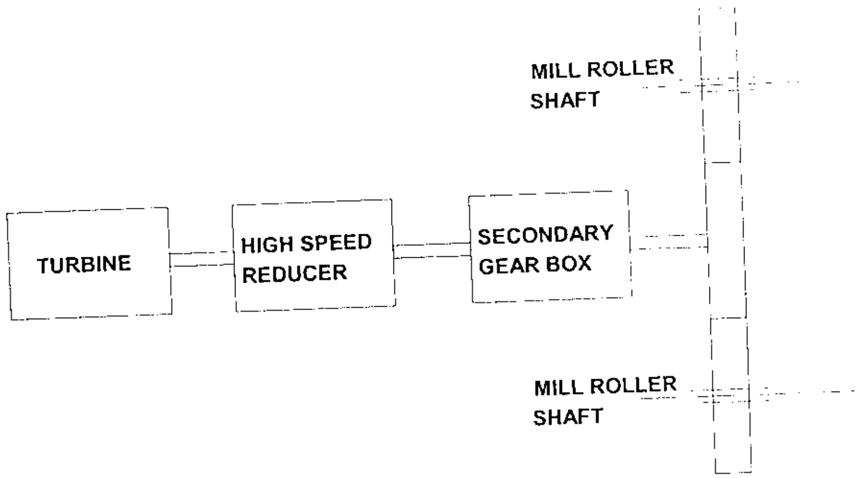

Fig. 6 SCHEMATIC SKETCH OF POWER TRANSMISSION

High speed reducer output speed $= \frac{1110}{5000} \times 4400$

$= 976.8$ rpm.

Secondary gearbox output speed $= \frac{27.54}{1000} \times 976.8$

$= 26.90$ rpm.

Speed of the top roller $= \frac{22}{104} \times 26.90$

$= 5.69$ rpm.

No of teeth in the top roller = No of teeth in the feed roller

= No of teeth in the discharge roller

= 15.

$\therefore$ Speed of the feed roller $= 5.69$ rpm.

Speed of the clutch shaft $= \frac{36}{15} \times 5.69$

$= 13.66$ rpm.

Speed of the inter – carrier shaft $= \frac{14}{15} \times 13.66$

$= 12.75$ rpm.

Linear Speed of the inter – carrier $= \Pi DN$

$= \Pi \times 12.75 \times 0.385$

$= 15.42$ m/min

CROSS CHECK

Linear speed of the inter - carrier = 1.1×Linear speed of top roller

$= 1.1 \times \Pi \times 0.83 \times 5.69$

$= 16.32$ m/min

4.3.4 Total load on slat

Total load acting/metre $= \frac{994.34 + 1272}{15.42}$

$= 146.97$ kg/m

Load acting throughout length $= 146.965 \times \sqrt{1.920^2 + 0.765^2}$

$= 303.76$ kg.

Pitch of slat $= 80.5$ mm.

Load acting on one slat $= \frac{303.76}{2066.79} \times 80.5$

$= 11.83$ kg/slat

4.3.5 Material Properties of Slat

Material : Steel

- Physical Properties:

Specific weight	=	0.0785 N/cm^3
Modulus of elasticity	=	2,06,000 N/mm^2
Modulus of Rigidity	=	85,000 N/mm^2
Co-efficient of linear expansion α	=	11.1 μm/ m °c.
Poisson's Ratio	=	0.3

- Mechanical Properties:

Minimum tensile strength	=	800 - 950 N/mm^2
Ultimate shear strength	=	700 N/mm^2

4.3.6 Elemental Description of Slat

Type of Analysis	:	Structural Analysis.
Type of element	:	SOLID 92 (Tetrahedral element)
No of nodes on each element	:	10 nodes.
Reason for Selection	:	Due to geometrical irregularity in Shape.
Type of loads	:	Applied as pressure on areas.
Type of Solver	:	Frontal Solver.
Type of solution	:	Stress-strain calculations.

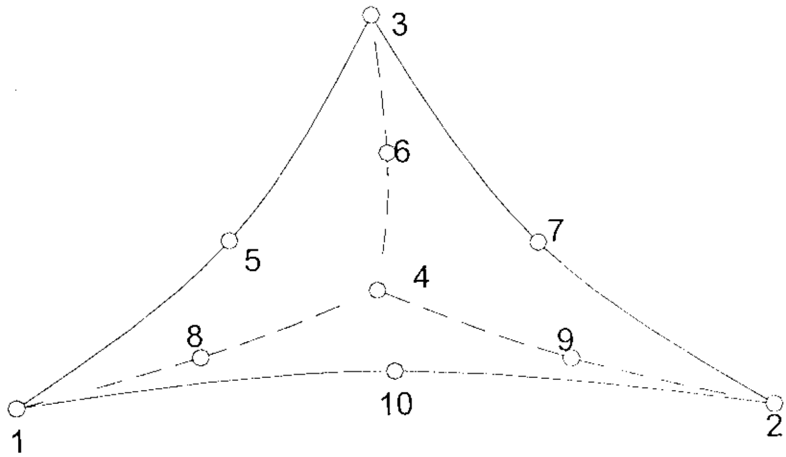

Fig. 7 SKETCH OF ELEMENT SHAPE FOR SLAT ANALYSIS

4.3.6 Loads and Constraints of Slat

1. Load acting on the surface of the slat in y direction = 11.83 kg
2. Displacements on the holes of the slat in x direction = 0 mm.
3. Displacements on the holes of the slat in y direction = 0 mm.
4. Displacements on the holes of the slat in z direction = 0 mm.

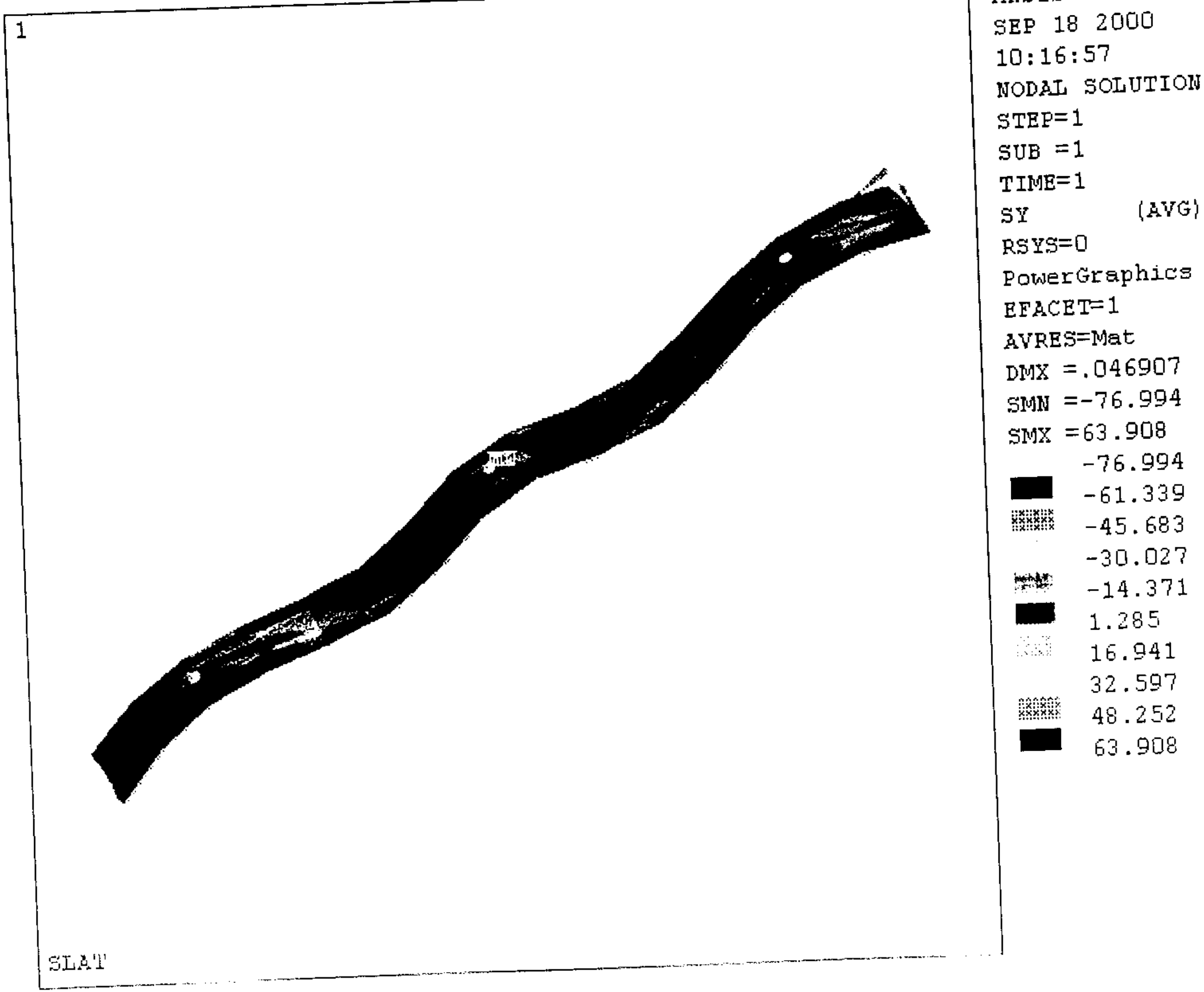

Fig. 8 STRESS DISTRIBUTION IN Y DIRECTION OF SLAT

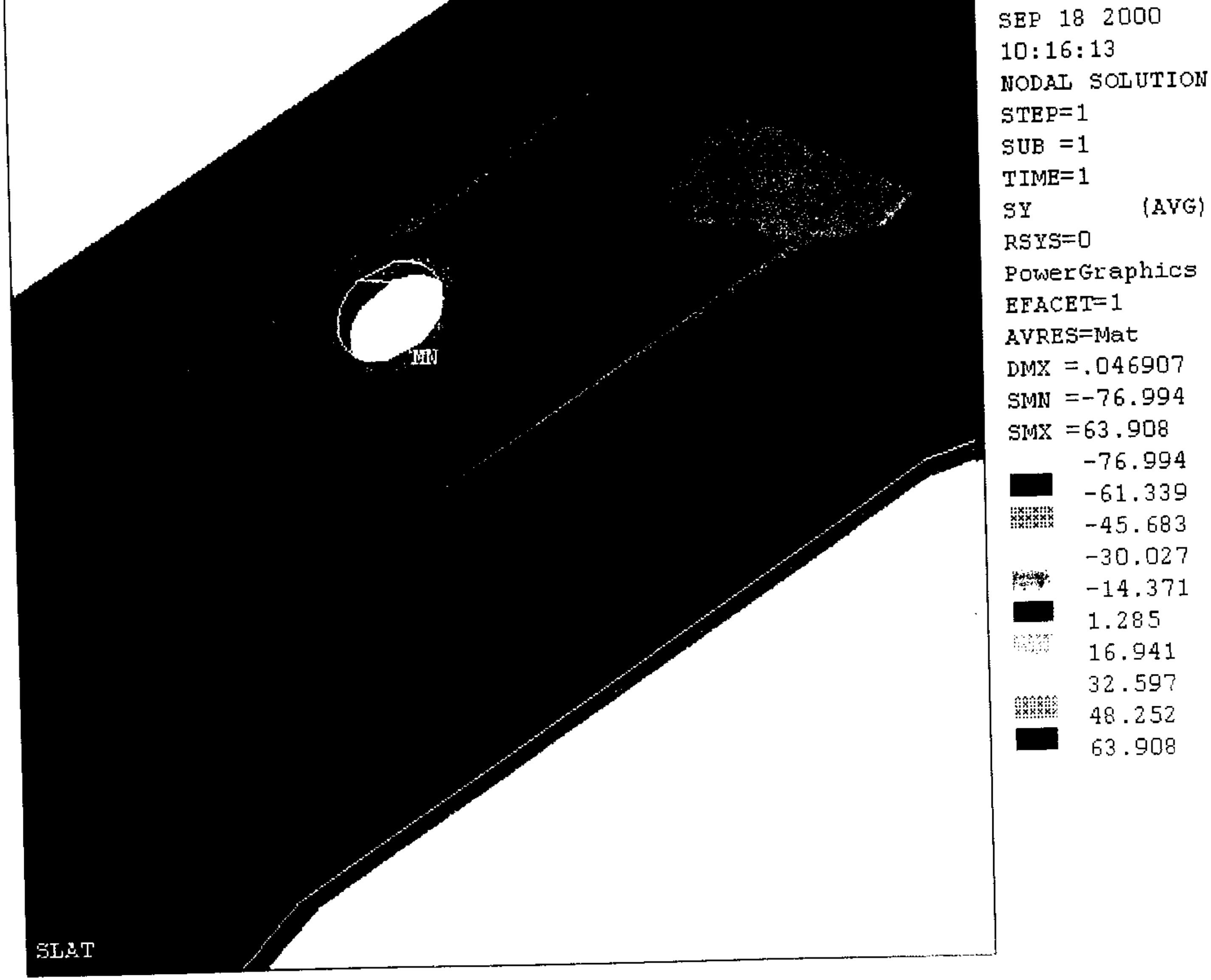

Fig. 9 STRESS DISTRIBUTION IN Y DIRECTION IN THE SHEAR AREA OF SLAT

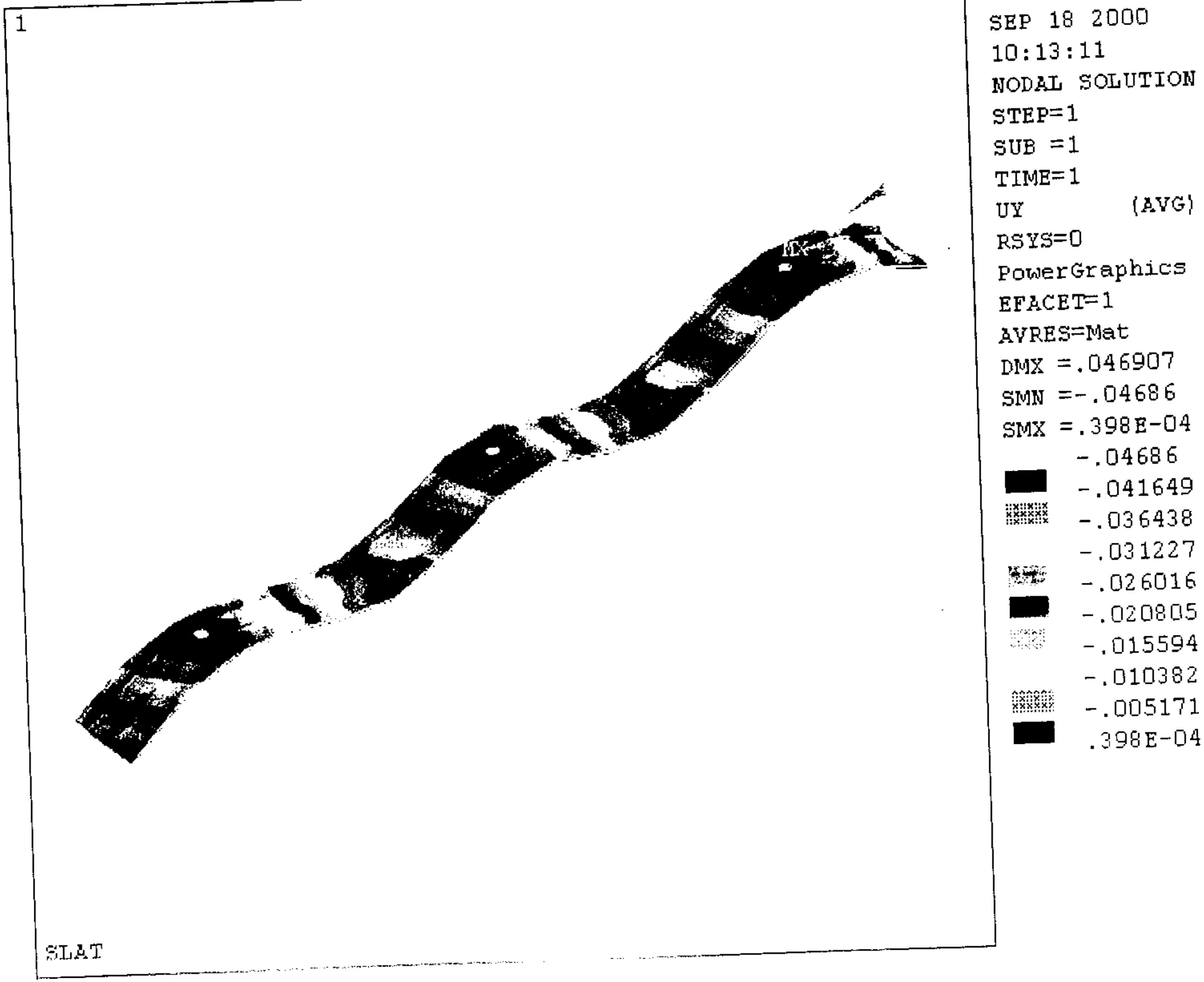

Fig. 10 DEFORMATION OF SLAT IN Y DIRECTION

4.4 Design Modification of Chain Link

Loads acting in link can be calculated from the ratio of amount of fibers present in cane, amount of fibers present in Bagasse, amount of juice or water added during the Imbibition system and self-weight of the slat acting on link. The load details are as follows:

4.4.1 Load due Power Transmission from Sprocket

Power consumed during conveying of Bagasse = 0.075 times Crushing rate

$= 0.075 \times 145.8$

$= 10.94 \text{ hp.}$

$$\text{Power} = \frac{2\Pi NT}{4500}$$

where $T = F.r$ is torque in kgf.m

$$\text{Force} \quad F = \frac{4500P}{2\Pi Nr}$$

$$= \frac{4500 \times 10.94}{2\Pi \times 12.75 \times 0.385}$$

$$= 3501.65 \text{ kgf.}$$

$$= 3500 \text{ kgf}$$

Here $\frac{1}{3}$ of the force acts in every link since there are three links parellel to eachother.

$\therefore$Force acting on each link on the hup pheripheral surface $= \frac{3500}{3}$

$= 1167 \text{ kgf.}$

4.4.2 Load acting on Body of the Link

Load due to slat weight = Load acting on the slat + Load due to Self-weight of the slat.

= 11.83 + 5.20

= 17.03 kgf.

Force acting on each link = $\frac{17.03}{3}$

= 5.67 kgf.

4.3.3 Material Properties of Chain Link

Material : Malleable Cast Iron

- Physical Properties

Specific weight	=	0.072 N/mm^3
Modulus of elasticity	=	1,00,000 N/mm^2
Modulus of Rigidity	=	35,000 N/mm^2
Co-efficient of linear expansion α	=	9.0 $\mu m/ m\ ^\circ c$.
Poisson's Ratio	=	0.23

- Mechanical Properties

Minimum tensile strength	=	320 N/mm^2
Ultimate shear strength	=	120 N/mm^2
Brinell Hardness number	=	149 HB.

4.4.4 Elemental Description of Chain Link

Type of Analysis	:	Structural Analysis.
Type of element	:	SOLID 187 (Tetrahedral element)
No of nodes on each element	:	10 nodes.
Reason for Selection	:	Due to geometrical irregularity in Shape.
Type of loads	:	Applied as pressure on areas.
Type of Solver	:	Frontal Solver.
Type of solution	:	Stress-strain calculations.

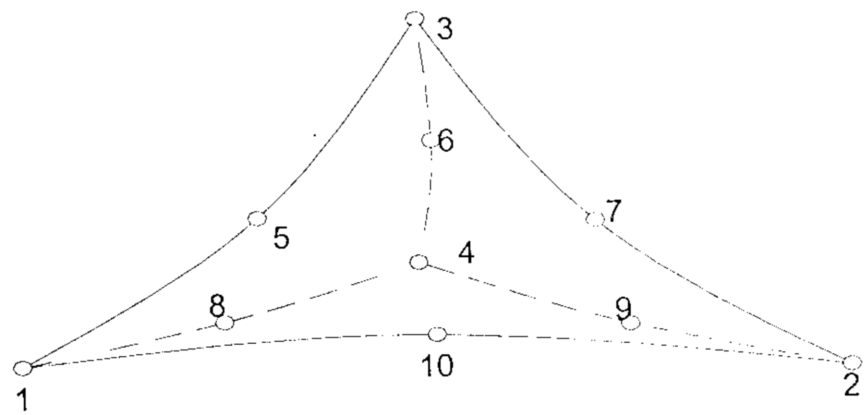

Fig. 7 SKETCH OF ELEMENT SHAPE FOR LINK ANALYSIS

4.4.5 Loads and constraints of Chain Link

1. Force acting on the hub peripheral surface in x direction = 1167 Kgf.
2. Force acting on the body of the link in y direction = 5.67 Kgf.
3. Displacement of the pivot points in link with bolts in X direction = 0 mm.
4. Displacement of the pivot points in link with bolts in Y direction = 0 mm.
5. Displacement of the pivot points in link with bolts in Z direction = 0 mm.

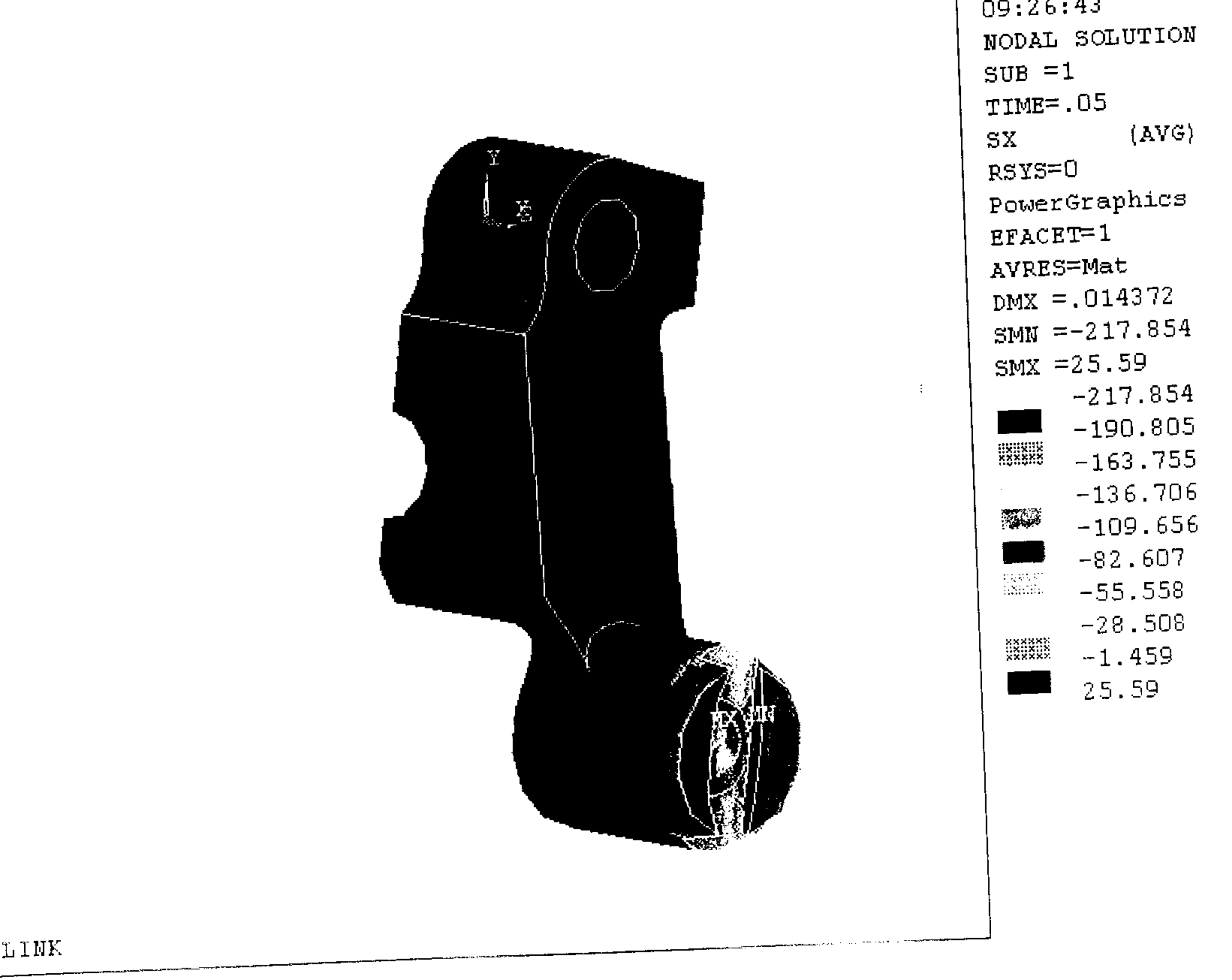

Fig. 12 STRESS DISTRIBUTION IN X DIRECTION OF OLD LINK DESIGN

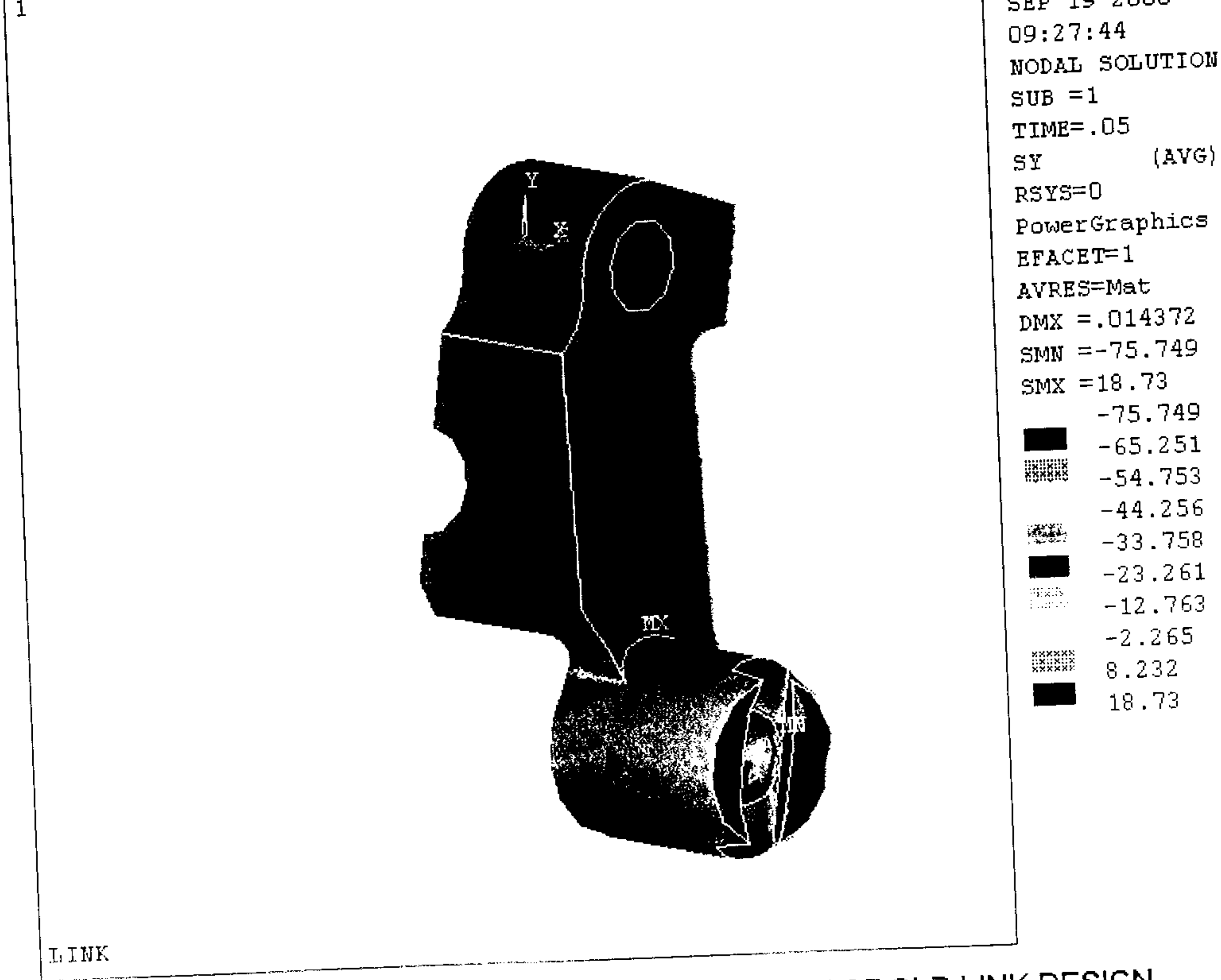

Fig. 13 STRESS DISTRIBUTION IN Y DIRECTION OF OLD LINK DESIGN

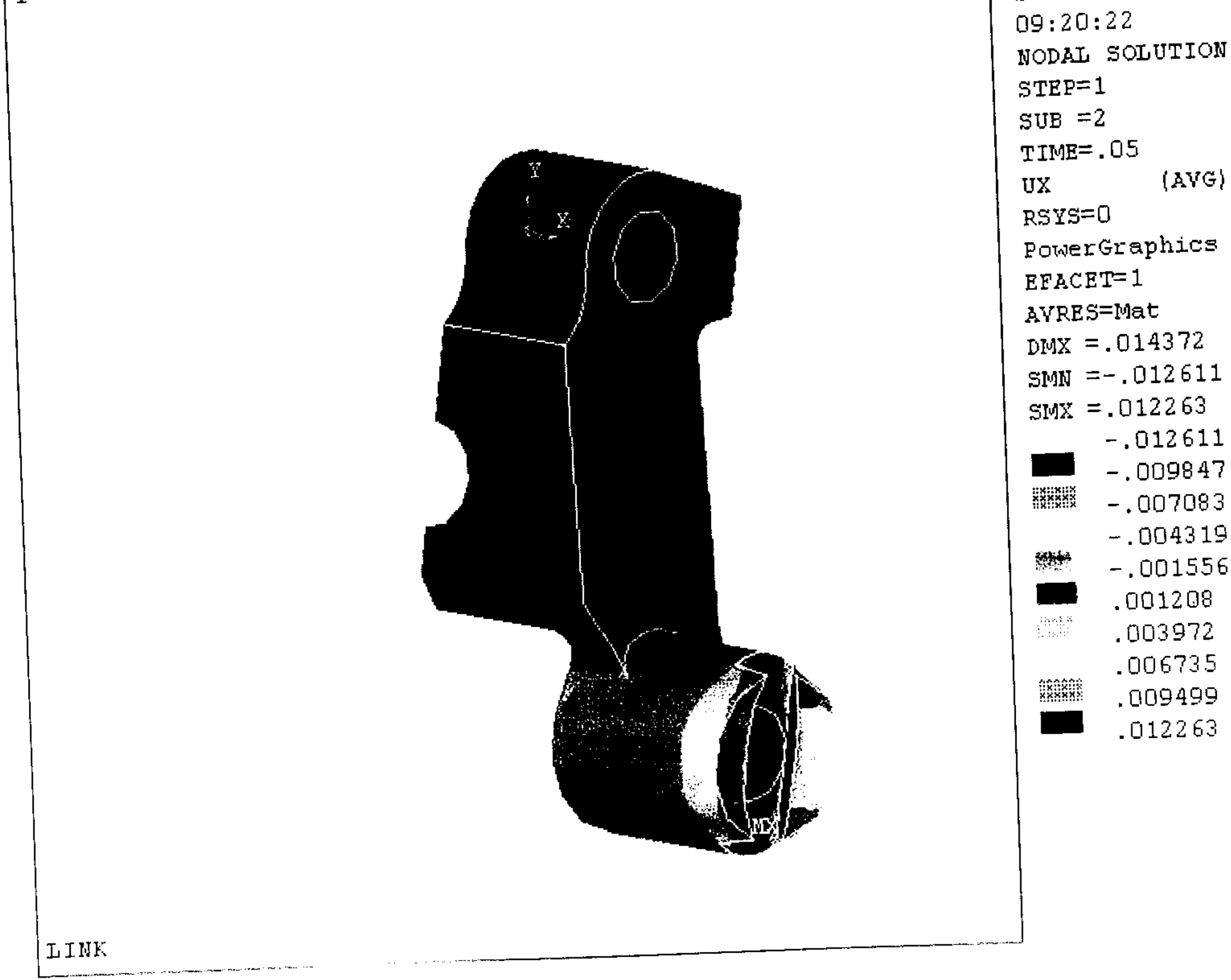

Fig. 14 DEFORMATION IN Y DIRECTION OF OLD DESIGN

4.4.6 Modified Design

The chain does not have constant linear velocity, since the chain does not wrap around the sprocket or straight edged pulley in the form of pitch circle, but in the form of pitch polygon. As a result, the meshing of chain link with the sprocket is noisy and not smoother and wear rate is more. In order to improve smooth meshing, the hub portion of the link must smoothly engage and disengage from the sprocket. So the hub portion of the link should be modified as tooth shaped profile in the case of silent chain. This profile will reduce the non-uniformity and wear rate of the link due to its smooth engagement and disengagement. The parameters required to modify the design are as follows:

1. Maximum height of the teeth = 0.82 x pitch
   = 0.82 x 80.5
   = 66.01 mm.
2. Angle of inclination with horizontal axis = 60 ° to 75 °

The analysis of modified design of link is as follows:

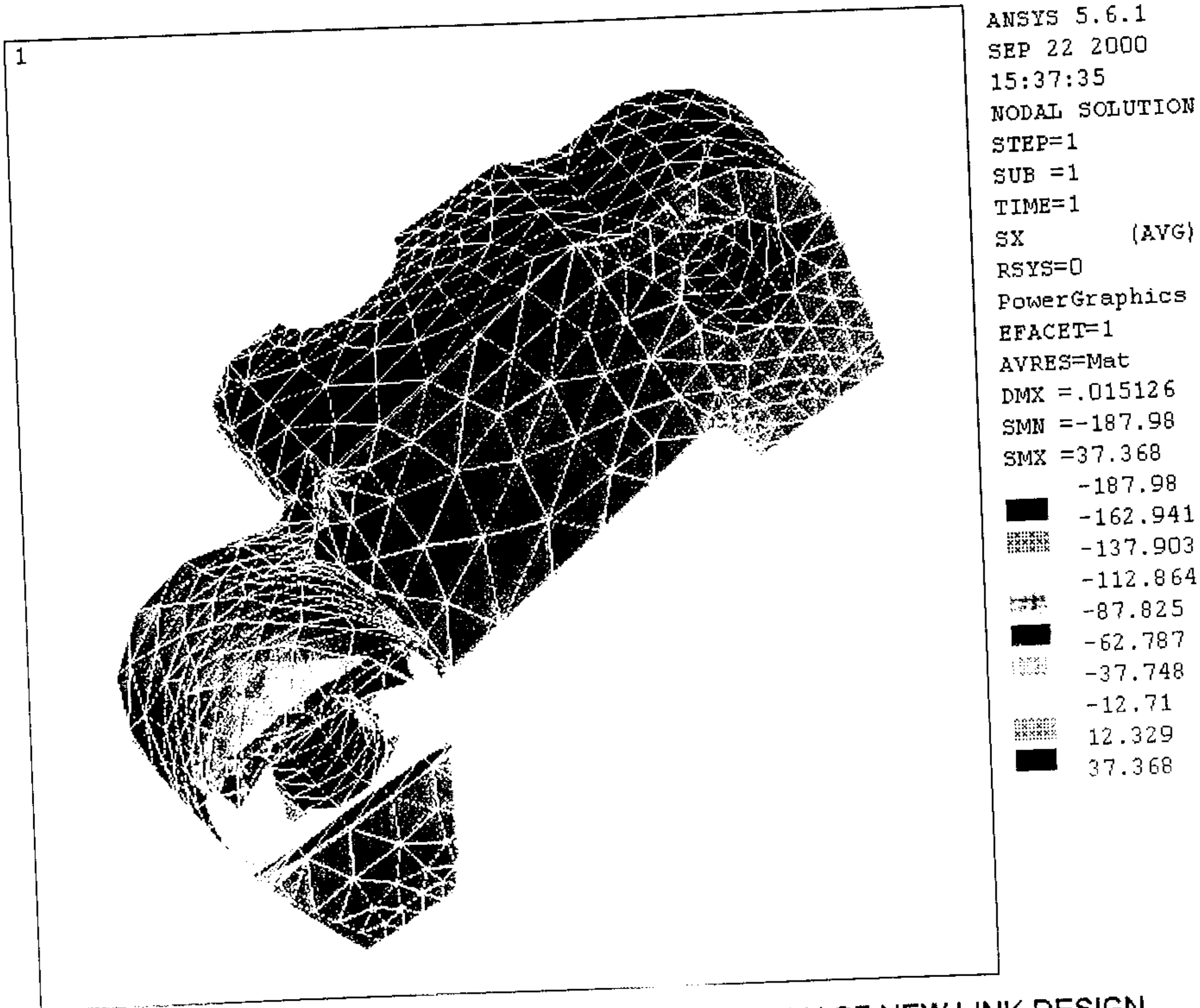

Fig. 15 STRESS DISTRIBUTION IN X DIRECTION OF NEW LINK DESIGN

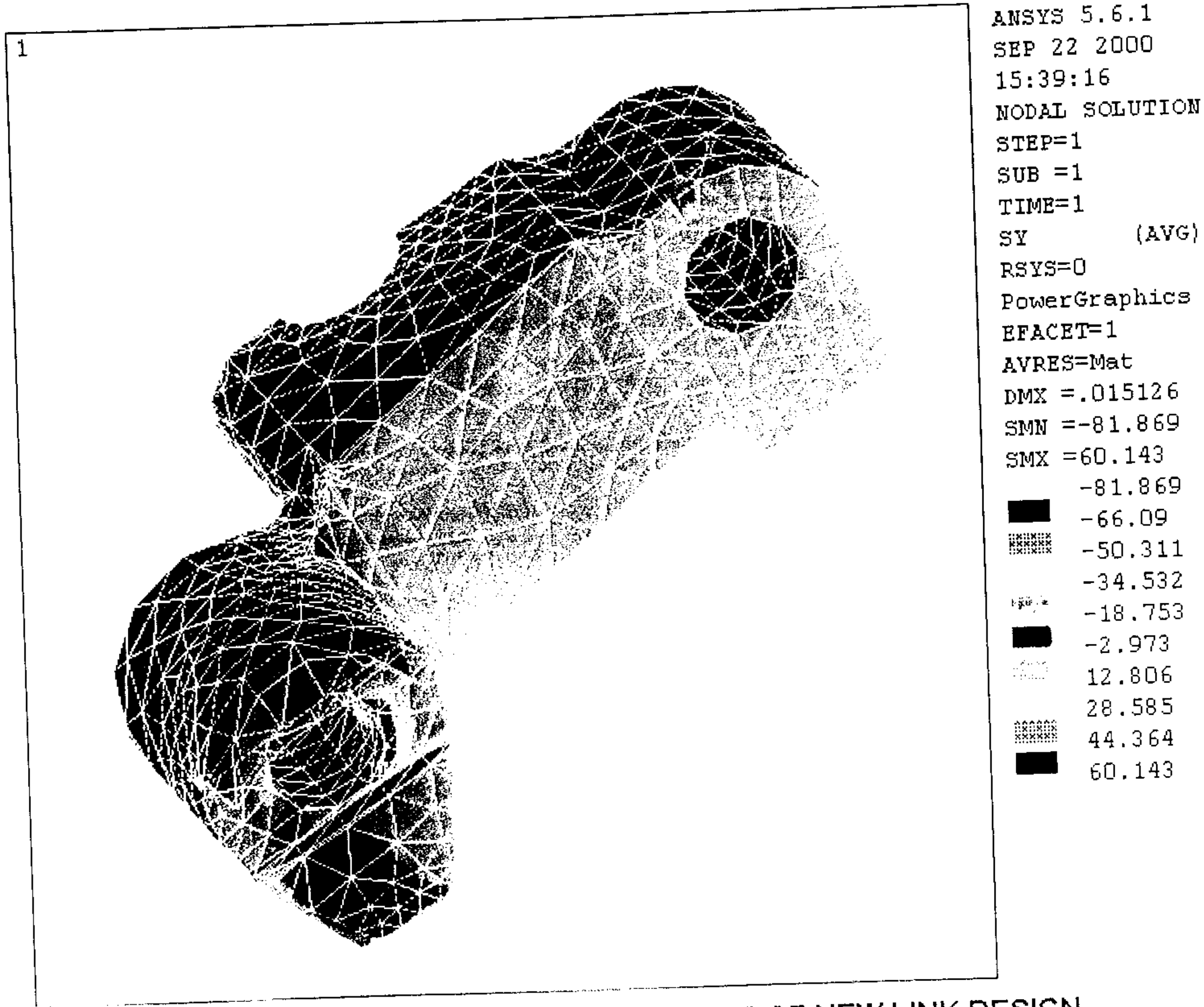

Fig. 16 STRESS DISTRIBUTION IN Y AXIS OF NEW LINK DESIGN

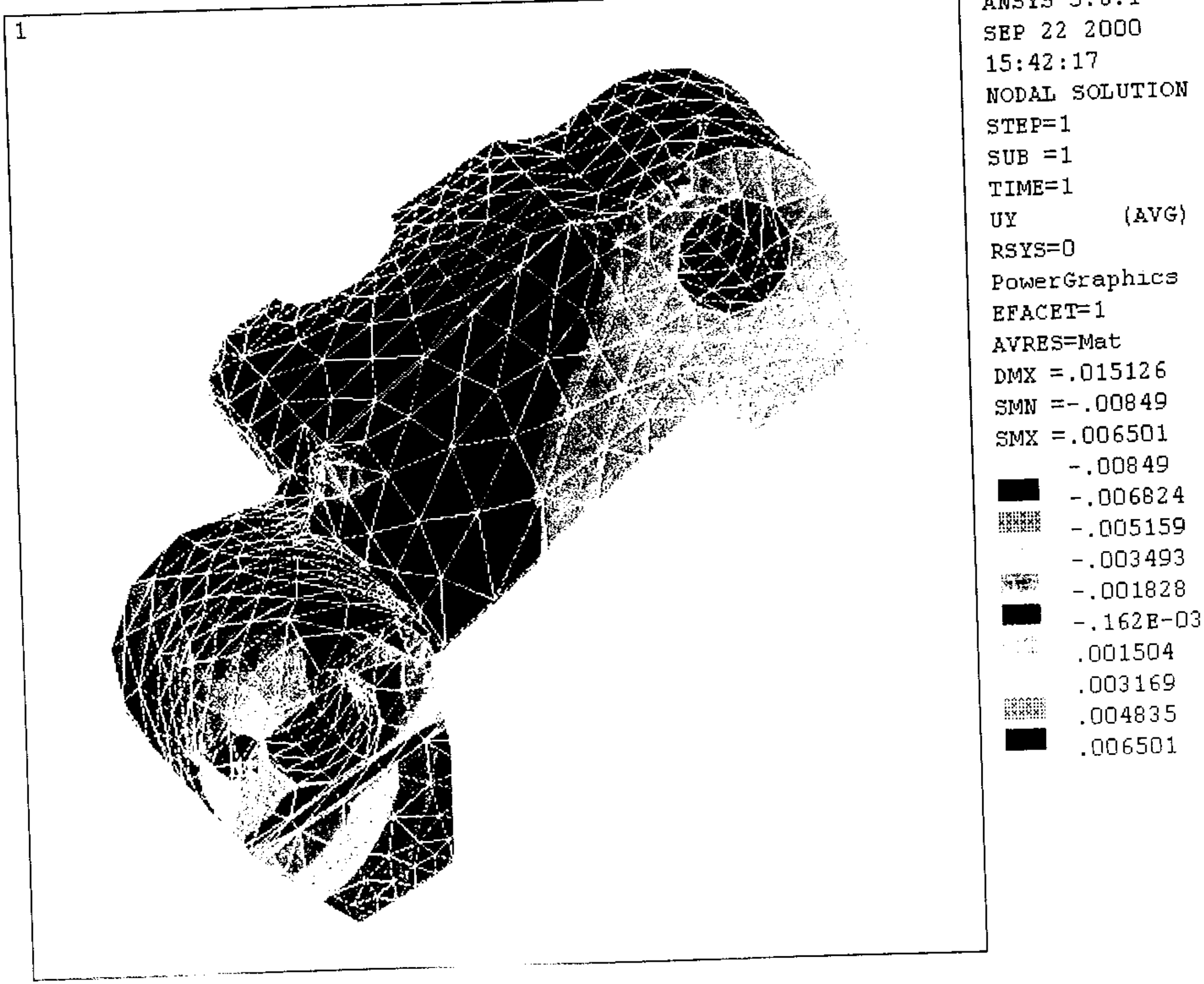

Fig. 17 DEFORMATION IN Y DIRECTION OF NEW LINK DESIGN

5 RESULTS AND DISCUSSIONS

The failure causes in the inter-carrier arrangement were studied and design modification of link and slat were made and analysed.

1. Slat Analysis

The analysis of the slat revealed that,

- Shear strength of the slat in y direction is 76.994 kg/mm^2, which exceeds its safety limit i.e. 70 kg/mm^2
- Deflection of the slat in Y direction is 0.0486 mm, which is negligible.

As the slat is dynamically stressed due to dynamic load, the shear stress is dynamically changing and it leads to failure.

Surface Hardening of the slat will reduce this failure at economical cost than any other method. There are number of surface hardening methods such as Carburizing, Nitriding, Carbo-nitriding, Cyaniding, Flame hardening, Induction hardening. Though the processing cost is increased, failure rate reduces comparatively and increases its life.

2. Chain Link Analysis

The analysis of old and new designs revealed that,

- The stress in the x direction reduces comparatively in new design i.e. 217.854 kg/mm^2 than in old design i.e. 187.98 kg/mm^2.
- The stress in the y direction increases slightly in the new design i.e. 71.749 kg/mm^2 than in old design i.e. 81.869 kg/mm^2.
- The deflection in the y direction comparatively reduces in new design i.e. 0.00849 mm than in old design i.e. 0.01269 mm.

Though the material cost is increasing due to the increase in weight, the smooth engagements and dis-engagements of the chain will reduce the chordal action and the non-uniformity in the linear speed of the chain. So failure rate of the link reduces comparatively than previous rate.

6 COST ANALYSIS

6.1 Cost Analysis for Slat

6.1.1 Old Design

Material Cost/kg	=	Rs. 25/-
Weight of one slat	=	5. 25 kg.
Cost of one slat	=	Rs. 156 /-
Average failure of slat (3 months)	=	30 nos.
Material cost / season (individual)	=	3 x 30 x 156
	=	Rs. 14,140/-
Group replacement / season	=	Rs. 32,760/-
Total cost / season / carrier	=	Rs. 46,900/-
Total cost / 12 carriers	=	Rs. 5,62,800/-

6.1.2 New Design

Increase in cost due to surface hardening	=	Rs. 15 /-
Average failure for 3 months	=	22 nos.
Material cost / season (individual)	=	3 x 22 x 170
	=	Rs. 11,220 /-
Group replacement cost	=	3 x 210 x 170
	=	Rs. 26, 690 /-
Total cost / carrier	=	Rs. 37,910 /-
Total cost / 12 carriers	=	Rs. 4,54,920 /-

6.1.3 Total Savings / Season in Slat

Total savings	=	Rs. 5,62,800 - 4,54,920
	=	Rs. 1,07,880 /-

6.2 Cost Analysis for Chain Link

6.2.1 Old Design

Material Cost/kg	=	Rs. 20/-
Weight of one link	=	1. 75 kg.
Cost of one link	=	Rs. 40/-
Number of links in each carrier	=	210 nos.
Average failure of link (3 months)	=	90 nos.
Material cost / season	=	3 x 90 x 35
	=	Rs. 9,450/-
Group replacement / season	=	210 x 40
	=	Rs. 25200/-
Total cost / season / carrier	=	Rs. 34,650/-
Total cost / 12 carriers	=	Rs. 4,15,800/-

6.2.2 New Design

Increase in volume	=	5. 291 cm^3
Increase in weight	=	0.25 kg
Increase in cost / link	=	Rs. 5 /-
Percentage reduction in failure	=	(217-187) / 217 x 100
	=	15.20 %
Average failure	=	76 nos.
Material cost / season	=	3 x 76 x 40
	=	Rs. 9120 /-
Group replacement cost	=	Rs. 21600 /-
Total cost / 12 carriers	=	Rs. 3,68,640 /-

6.2.3 Total Savings / Season in Link

Total savings	=	Rs. 4,15,800 - 3,68,640
	=	Rs. 47,160 /-

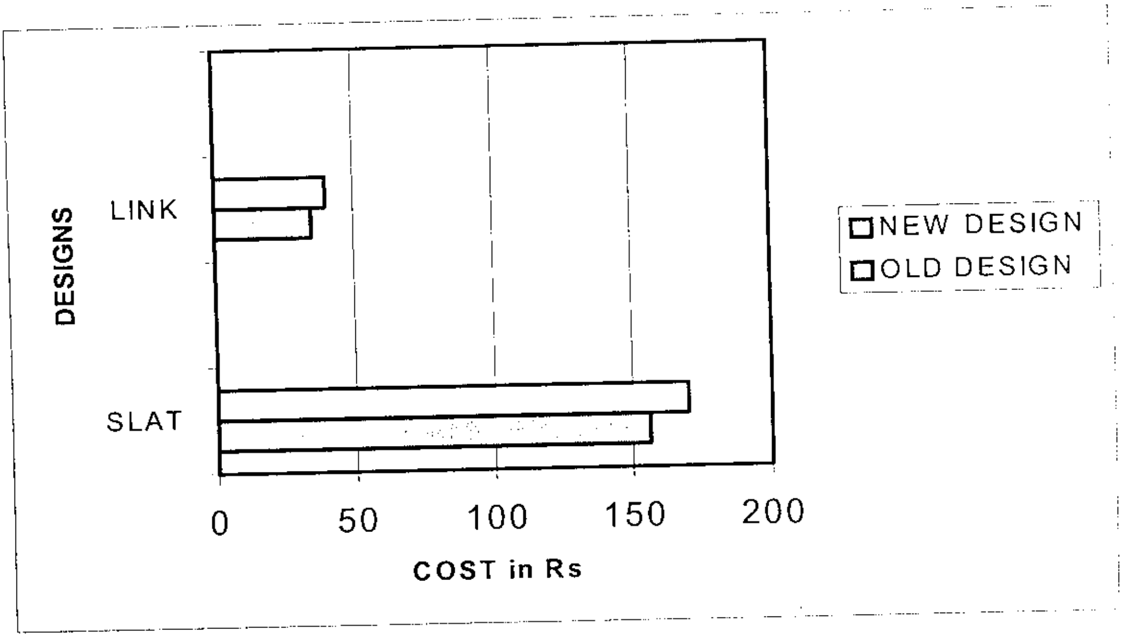

Fig. 18 UNIT COST COMPARISIONS

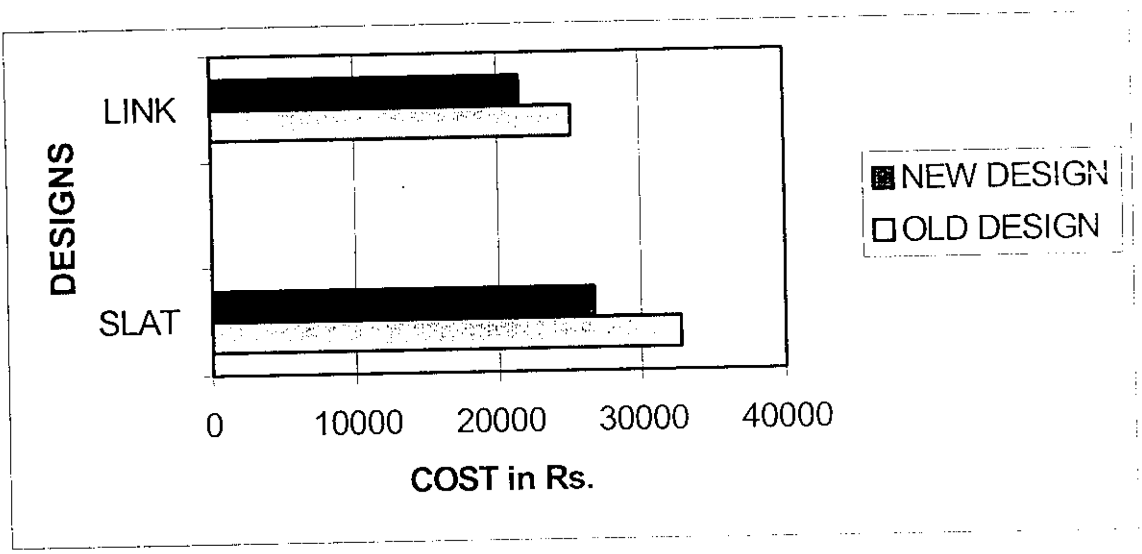

Fig. 19 GROUP REPLACEMENT COST COMPARISIONS

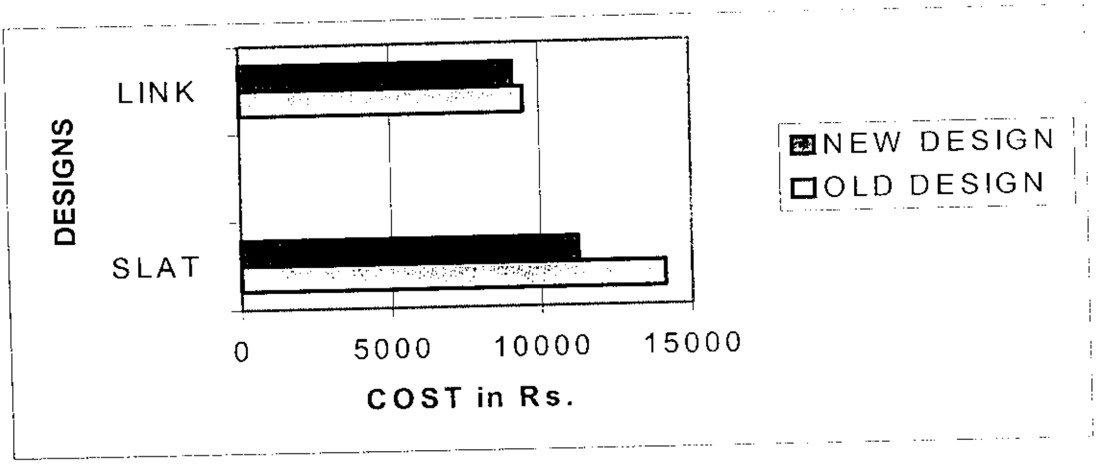

Fig. 20 MATERIAL COST COMPARISIONS

6.3 Total Savings / Season of modifying Design

Total Savings due to alteration in design = Rs. 1,07,880 + Rs. 47,160

= Rs. 1,55,040/-

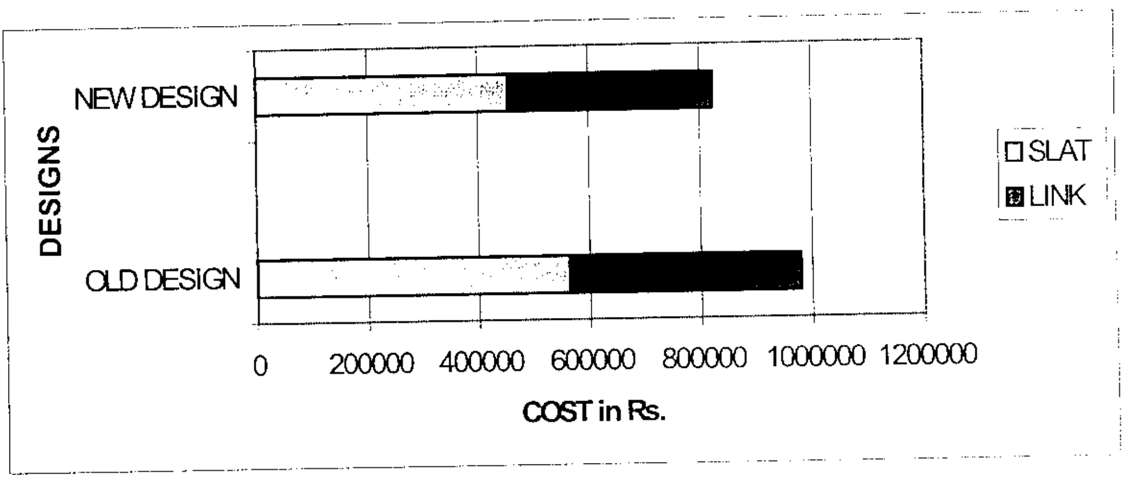

Fig. 21 TOTAL COST COMPARISIONS

CONCLUSION &
SCOPE OF FUTURE WORK

7 CONCLUSION AND SCOPE OF FUTURE WORK

The causes for failures of link and slat assembly were studied. The designs were modified to suit the space available in the mill section. Then the suggested designs were analyzed and the results of analysis clearly points out the modified design will redúce wear rate, increases the life of the arrangement and reduces the cost of replacement by Rs. 1,55,040.

The suggested design can be implemented by creating a physical model and tested in various load conditions in-order to prevent the stoppage due to the external unnecessary problems. This preliminary attempt of modifying the design helps in making various approaches in optimizing every process or components in the company in near future.

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