Design & Analysis of 'INDUSTRIAL MATE' a Semi-Automatic Die Loader

Karan Gujaran[1], Mihir Gohil[2], Mr. Mahendra Shelar[3]

[1,2]Student, Mechanical Eng. Dept, Thakur college of Engineering and Technology, Mumbai, Maharashtra, India.
[3]Assistant Professor, Dept. of Mechanical Eng., Thakur college of Eng. And Tech., Maharashtra, India.
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Abstract – Industrial mate is an advanced form of a material handling equipment. It utilizes basic mechanical and robotic principles in order to elevate bulky materials or dies lifting it right from the ground level without use of any external means and transfer it from one point to another. The prime movers used are electrically operated by a panel controller and are powered by a portable battery source.[6] The main objective of the research is providing an effective way of material handling with minimum human intervention in order reduce risk of injuries to the shopfloor workers.

***Key Words*: Die loader, Material Handling, Back pain Workplace injuries, Automation, Suction gripping, lifting Mechanism, Industrialization, Power screw system.**

1. INTRODUCTION

In recent years in the world of industrialization there has been a lot of research in the field of manufacturing and robotics. Emphasis has been put up on the robotics & automation world to ensure a quick, safe and easy working in the shop floor of the commercial industries of manufacturing.[8] Now as the world is moving towards automation, industries are getting equipped with more advanced systems in order to reduce human efforts and time utilization and to increase productivity and safety of workers. The main focus of the project is to provide assistance to the workers working on the shop floor such that they get a better working experience with reduced risk of injuries.[6]

1.1 Problem definition

In this era of innovations, world is looking forward to industry 4.0 & robotics is an important factor responsible. We often tend to forget that manufacturing can be a dangerous industry as there are always chances of health hazards and injuries to the workers working on the shop floor. Most of the non-fatal injuries happen due to the lifting and mishandling issues. According to the Bureau of Labour Statistics, in the last recorded year, there were approximately 2.9 million non-fatal workplace injuries and illnesses reported by private industry employers.[9] In order to ensure safety and well-being of workers we need to develop a solution that can provide help to lift up the load from the shop floor and to elevate it to a specific.

1.2 Scope of the project

According to the 2019 survey by Bureau of labour statistics 31% of workers had suffer from severe back pain issues due to lifting heavy loads.[9] A staggering 80% of adults working in any industry are estimated to experience a back injury for lifetime. This is a prevailing issue in every sector. However, when it comes to manufacturing sector the chances of injuries are much higher, especially in a die manufacturing unit where workers have to work with bulky dies all the time. The project majorly focuses on providing a solution in accordance to a small-scale die manufacturing unit.

2. LIMITATIONS OF CONVENTIONAL LOADERS

When it comes to a small-scale die manufacturing firm, in order to handle and move the heavy dies generally forklifts and scissor lift loaders are employed.[2] Fork lifts are used inside the inventories whenever the material has to be moved up or down from a high rack. [1,2] But forklifts require the load to be placed on a special wooden platform which has room space for the prongs of the forklift to enter and lift it. [2] The vertical race of forklift extends in upward direction hence it is not considered as a compact equipment.

On the other hand, conventional die loaders which utilizes scissor lift mechanism is much compact, much cheaper and suitable to carry bulk load on the roller platform placed on top but, it requires manual loading and unloading effort and a constant actuation force from the operator to keep the load elevated. There is no proper gripping and holding force on the work material hence there are chances that work load may slip off the platform while in motion.

So, we can conclude that although this conventional equipment provides a solution to the problem but are still not effective enough as they have some limitations.

The main aim of this design is to overcome these limitations and provide a much better solution.

3. SEMI-AUTOMATIC DIE LOADER

Previously we concluded that both fork lift and scissor lift die loader that are usually used in any die manufacturing industries have their own advantages and limitations. Comparatively scissor lifts can be more effective and feasible in a small-scale industry. We can focus on enhancing the performance of a scissor lift die loader by bringing in some functional modifications.

As identified previously there are three major limitations of a conventional die loader:
1. Manual Loading/Unloading effort
2. Constantly, manual actuation force is required
3. No proper gripping on the work load.

To solve these issues, we have come up with three distinctive feature modification to the conventional design.

3.1 Electrically powered Scissor lift

The scissor lift is powered by an electric motor coupled to a power screw assembly attached to the bottom of the scissor lift. The rotational torque from the motor is used to generate the liner thrust force by the power screw which when applied on the scissor links eventually generates the required lift force used to lift the work load in the vertical direction. Previously where operator had to constantly press the hydraulic pedal in order to keep the load elevated, now have to simply press a button on the control panel and the load will be lifted easily without any extra effort.
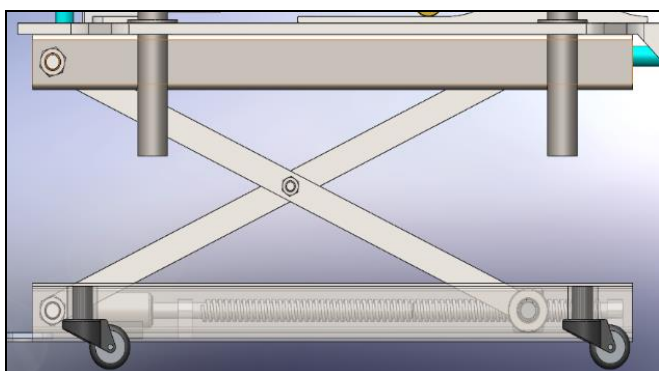

Fig 1: Electrically powered Scissor lift

3.2 Extender arm module

This is employed to solve the manual loading and unloading issue. It comprises of a power screw arrangement electrically operated to generate a forward linear motion and a special cam arrangement to provide a small initial lift such that the work load can be easily placed on the platform. When it is controlled synchronously with the suction gripper module it is capable of lifting the load right from the shop floor surface and can place it on the carrier platform without causing any damage to the work material. It has a fix plate fastened over the top channel of the scissor lift. This fixed plate carries the carrier platform frame which is directly welded on this plate structure. The carrier platform is made of series of rollers which ensures easy movement of the work load on the platform. There is a moving plate on which motor and power screw arrangement is placed and this plate moves relatively with fix plate in upward direction as the follower ascends the cam profile. The movable plate is constrained and guided by four guide pillars. Altogether this arrangement facilitates easy and effective way of loading the work material on the carrier platform without the help of any external means and in a similar way it is also able to unload the material from the carrier platform onto the destination of desired level.
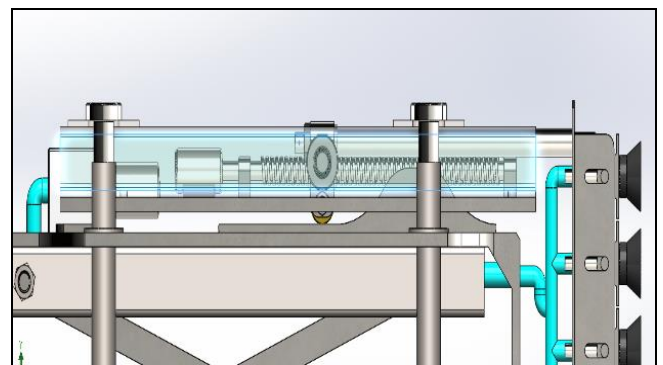

Fig 2: Extender arm module

3.3 Suction gripper module

This base plate of this module is attached to the push rods of the extender arm module. This module serves the purpose of establishing a firm grip on the work material surface while it is being placed on the roller platform. As the name defines it utilizes suction pressure generated using a vacuum pump arrangement to grip the work surface tightly.[5] There is a series of movable plates each containing at least two suction

cups which are connected to the vacuum pump via vacuum hose.[4] Each plate is guided by straight slots and pin to ensure a constrained rotational and linear motion and it also has guide pins which are spring loaded. This arrangement allows the plates to self-adjust themselves according to the curvature and size of the work material and due to the spring force once the work material is removed the plates can restore back to the original position.
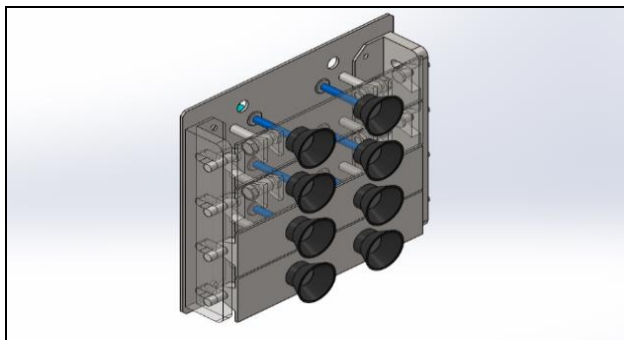

Fig 3: Suction Gripper module

4. DESIGN OF INDUSTRIAL MATE

When the above-mentioned modifications are to be applied to the basic design structure of the conventional die loader the resulting design would be a completely innovational with semi-automatic controls providing the most effective way of handling bulky dies in a small-scale industry. The fundamental structure design is accomplished by combining the dominant design features of a mechanical forklift and manual scissor lift die loader. Additionally, power screw systems and Cam mechanisms are utilized for improved functionality of the system.

4.1 Specifications and Requirements

The prototype of INDUSTRIAL MATE is designed considering the following functional specifications.

Table -1: Specification

Sr.	Parameter	Value
1	Max. Material Load Capacity	50 kg
2	Avg. Design Load Capacity	25 kg
3	Overall Dimensions	L = 100 cm, B = 30 cm H(min.) = 20 cm H(max.) = 53cm
4	Lifting velocity	3 cm/s
5	Self-weight (counter weight)	53 kg
6	Maximum Elevation	33 cm
7	Factor of safety (FOS) (for overall design)	5

The proposed design is to be initially tested as a prototype model hence the specifications and parameters are also set accordingly. However, during the deployment phase, the parameters will be adjusted and based on the empirical calculations established overall design changes can be executed easily.

4.2 Design Calculation

For the design validation by theoretical calculations, basic principles of engineering mechanics and general theories of failure like maximum principal stress theory and maximum shear stress theory is used. Using these theories critical stresses and critical dimensions for each and every component is determined and evaluated in accordance to the considered factor of safety of 5 and the loading constraints.

The most critical and important part of the design is the scissor lift assembly. Since it has to bear with the maximum total load and along with it due to the cantilever type loading moment balancing is also difficult.[3] In order to determine the stability condition suitable for all levels of inclination static and dynamic analysis is done.[7]

Static analysis at 45° angle of inclination [7]

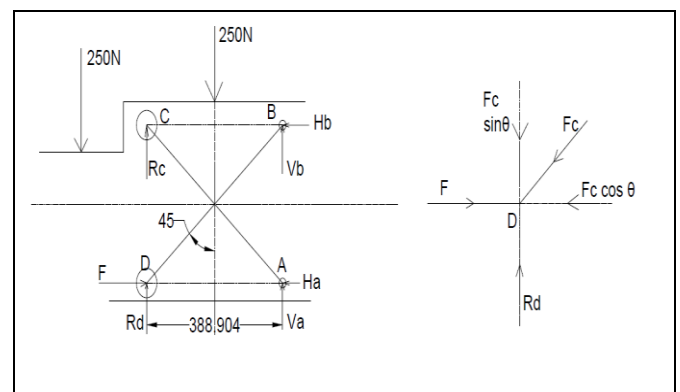For Static analysis basic equilibrium principle is used.

Fig 4: Loading diagram of scissor lift

Now, let us consider that scissor lift is locked at an angle of 45°

Model has symmetricity about X-X axis, therefore

$R_C=R_D$, $H_A=H_B$ and $V_B=V_A$

Considering that a Max load of 500N acts on the system in Y direction

We can apply equilibrium conditions

$\sum F_y = R_D + F_A = 500N$

$\sum F_x=0$; $\therefore F = H_A$

where F is locking force exerted by lead screw.

$\sum M_a =0$;

$R_D*550\cos\theta = [250*(550/2)*\cos\theta] + [250*(550*\cos\theta+160)]$

Considering, $\theta= 45°$

$\therefore R_D= 477.83N$ & $V_A= 22.17N$

Since similar adjustment is done on the adjacent side so the reactions get distributed

$R_D=R_C= 238.915$ N $V_A=V_B= 11.085$ N

Now let us apply Equilibrium condition at node D,

$F_C*\sin\theta = R_D$

Considering, $\theta= 45°$

$F_C = 337.8768$ N

$F_C*\cos(45) = F = 238.915$ N

Total force = 477.83 N

Similarly, at other values of θ forces are calculated and tabulated below.

Table 2: Results of Static analysis

θ	R_D	$R_D/2$	V_A	F_C	F
20°	452.39	226.2	47.61	661.35	621.46
30°	458.98	229.49	41.02	458.98	397.49
45°	477.85	238.92	22.15	337.89	238.92
60°	520.45	260.25	-20.45	300.48	150.24
70°	587.64	293.82	-87.64	312.67	106.93
75°	655.99	327.99	-156	333.05	86.19

From the above analysis some important points can be deduced.

- F represents the holding force required to hold the scissor lift in stable position. As θ increases its value goes on decreasing hence the maximum value of F is **621.46N**. This force will be provided by the motor hence motor selected should have the capacity more than the specified limit.
- The compressive forces on scissor links are initially very high but it starts decreasing with increase in θ, after 60° it again starts increasing under the action of vertical load.

- As θ increases, load on the rollers on front end increases and that on the fixed support decreases. After θ crosses 60°, the direction of V_A reverses and starts increasing up to 150N till θ reaches 75° This shows that we need to have an additional weight to compensate this reaction force so as to prevent any unbalance condition of the scissor lift.

Dynamic analysis of Scissor lift

Dynamic Analysis can be done using Work-Energy Principle,

Load to be lifted = 500 N (50kgf),

Speed of motor (N) = 150 rpm (assumed)

Radius of lead screw shaft = 30 mm (assumed)

$V = r*\omega = 0.03$ m $* [(150*2\pi/60)$ r/s]

$V = 0.471238$ m/s

$\therefore \Delta KE= KE_2 – KE_1= [0.5*50*(0.471238)^2] - 0$

$\Delta KE= 5.5516$ J

Work done externally = $F*s = F * 0.33$

Work done against gravity = $m*g*h = 50*9.81*0.33$

Total work done = Change in Kinetic energy

$F (0.33) -(50×9.81×0.33) = 5.5516$

Total force $F_T= 507.32$ N

$\therefore$ each side F = 253.66 N

Table 3: Results of Dynamic analysis

N(rpm)	V(m/s)	F(motor) (N)
75	0.2317	494.705
150	0.4712	507.352
200	0.6283	520.406
300	0.9425	557.791
400	1.2566	610.1242
500	1.5707	677.3787

- From dynamic analysis we come to know that initially motor has to rotate with higher velocity in order to generate high forward thrust but as the angle increases velocity of motor can be decreased. In other words, power consumption of motor is initially high and it decreases as the angle increases.
- Maximum thrust force required from the power screw is approx. >630N at a speed > 400rpm.

4.3 Selection of Components and Materials

Table 4: Standard component selection

Sr.	Component	Model	Specification
1.	Motor	RS775	12V Type DC Power: 10W Torque: 2Nm, Speed: up to 4000 RPM
2.	Vacuum Pump [5]	ISC1628	12V Type DC Power: 10W Pressure: 0.7 bar Flow rate: 50 LPM
3.	Bearing 1 (DGBB)	SKF6000	Diameter: 10mm $C=3600N$, $C_0=1900N$
4.	Bearing 2 (DGBB)	SKF6006	Diameter: 30mm $C=10400N$, $C_0=7100N$
5.	Battery Source [6]	Amaron Black 18	Voltage: 12V DC Capacity: 50 Ah
6.	Suction Cup [4]	VD50	Diameter: 50mm Volume: 13.5 cm^3 H force: 50 N V force: 80 N
7.	Power Screw	SQ20X6	Single start, Self-locking. $D_c=14mm$, $D=20mm$ Pitch= 6mm, Lead= 6mm Helix angle: 6.41^o
8.	C Channel [3]	50X25X5	Long width: 50 mm Short width: 25mm Thickness: 5mm

The above-mentioned components are selected based on a proper calculation of the design requirements, market availability and cost consideration.

Table 5: Material Selection

Sr.	Material	Yield strength	Application
1.	Mild Steel C20	260 MPa	Plates, Supports & Guides
2.	Mild Steel C30	300 MPa	Support frames, Cams and follower
3.	Mild Steel C45	360 MPa	Scissor links
4.	Stainless Steel	250 MPa	Handle bar
5.	Hardened Steel 30C8	465 MPa	Power screw and nut

The material selection is based upon perspective determination according to the loading condition of a components or sub-assembly. When loading is critical material of high strength is selected and vice versa.

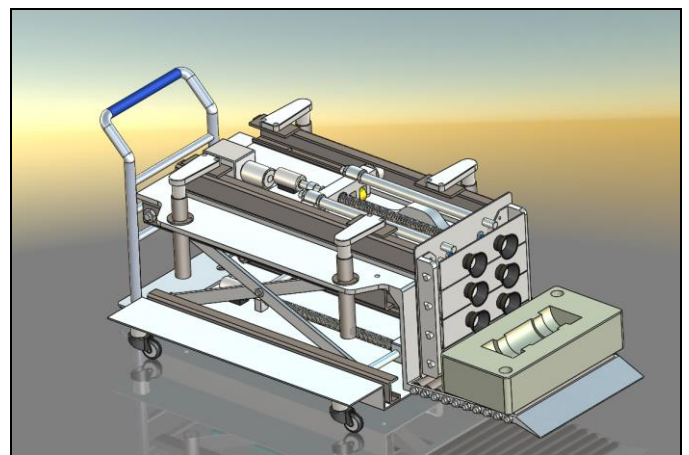## 5. DESIGN SIMULATION AND ANALYSIS

5.1 CAD Model
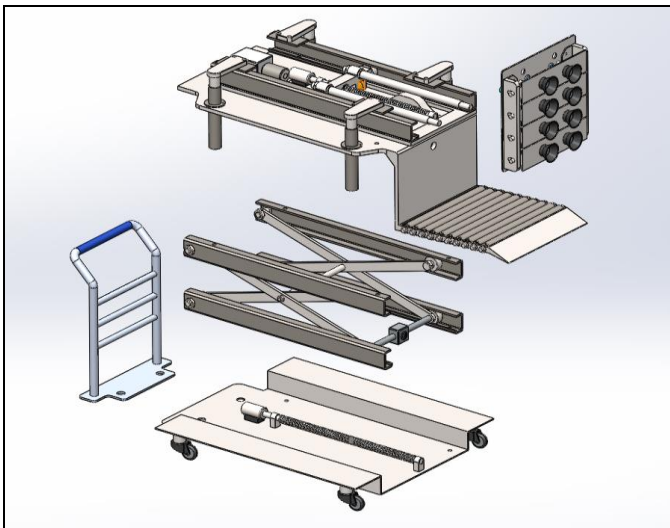

Fig 5: Rendered Model

Fig 6: Exploded View of the model

The CAD model is prepared using Solidworks interface. Interference detection and collision detection were performed on the model. Based on the results model was optimized and rendered into a final design model.

5.2 Testing & Analysis of CAD Model

Theoretical calculations give ideal values which may differ from the actual results since there are several assumptions which may cause deviations. So, to reassure the design and to test the model with a better algorithm computational method of design validation is incorporated. In this previously prepared CAD model is analyzed using ANSYS software.

The scissor lift forms the basic skeleton of the project and is majorly focused on fulfilling the main objective which is to lift the entire load to a maximum elevation. Hence the stress levels and the loading conditions are maximum and has to be properly managed to ensure safe and sound execution.
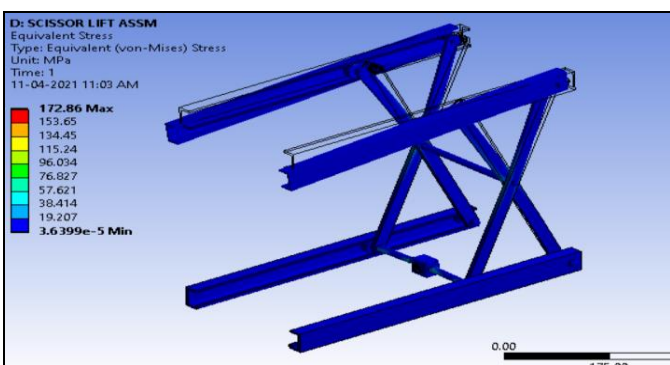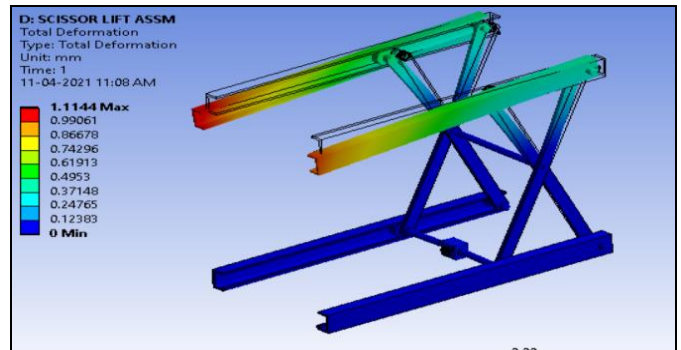

Fig 7: Von Mises stresses

Fig 8: Total Deformation

Results	Minimum	Maximu...	Units	Time (s)
Total Deformation	0.	1.1144	mm	1.
Equivalent Stress	3.6399e-005	172.86	MPa	1.
Maximum Principal Stress	-20.558	213.97	MPa	1.
Safety Factor	1.4462	15.	Units Unavailable	1.
Structural Error	1.1016e-013	0.61349	mJ	1.
Shear Stress	-83.681	21.273	MPa	1.

Fig 9: Analytical Values

The above analysis shows that the entire load acts up on the top C channel and the axial thrust force generated by the power screw coupled to motor acts on the power nut arrangement. The bottom C channel is given fix support and the stress levels are calculated. The maximum equivalent stress acting on the assembly is **172.86 Mpa** and the maximum factor of safety is **15**. Hence the assembled model is said to be safe against all kinds of catastrophic conditions.

6. FUTURE SCOPE

Since it is designed as a semi-automatic die loader it can also be made fully automatic die loader as a friendly robot in the manufacturing units. The main focus of the project is designing of a basic solution for the lifting of heavy objects and hence the proposed device has to be manually controlled by a human operator. However, in the future the device has the ability to be made completely autonomous by using microcontrollers and program logics to control the movements and functions of the system.[8] Such that it can locate the object that is to be lifted, carry it to the machine table, lift it up and place it on the machine table according to the inputs given to it. In future INDUSTRIAL MATE can be made as complete automation which will lead to better compatibility with workers and improved work efficiency.

7. EXPECTED OUTCOMES

i. The equipment will be completely self-loading, independent of any external means. Thus, reducing overall cost of material handling.
ii. It will provide a safer working environment by reducing the risk of injuries at the shop floor.
iii. It will reduce the human effort required to get the work done. Hence work rate will increase.
iv. It will provide an efficient and faster way of material handling. This improves the overall productivity of the manufacturing process.
v. The equipment will be compact in design and portable hence will occupy very minimal floor space. [3]
vi. It will be Environment friendly as it operates on electrical power supply. [6]

8. CONCLUSION

This Design is basically intended towards devising a proper and convenient equipment for material handling in a small-scale Die Manufacturing unit. The main focus of the project has always been to eliminate the threats imposed to workers at the shop floor while handling bulky work load or work material. The proposed architecture is a compact and a robust design capable enough to lift average load of 25 to 30 kg to maximum load of 50 kg gripping it right from the floor surface without any external help. It is not going to completely eliminate human intervention for getting the work done, however it will definitely be a helping hand to the workers at the shop floor. Keeping this intention in mind it has been named as 'INDUSTRIAL MATE' which means a friend/mate to the industrial workers & the industry.

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