INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING

ISSN (ONLINE): 2321-3051

Vol.3 Issue.2,

February 2015.

Pgs: 18-27

# VIRTUAL STABILITY OF FORKLIFT TRUCK IN CAD

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## Abstract

Forklifts are used for material movement from one place to another. The purpose of the study was to find out the effective method for stability testing of the industrial forklift truck with the help of CAD model of the forklift. The forklift should be stable along lateral and longitudinal axis while moving with and without load on plain ground as well as on slopes specified. These methods of stability testing and their values in different conditions are specified in IS4357. This paper focuses on procedure for stability testing of forklift in CAD before actual manufacturing of the truck.

***Keywords:*** *Forklift, stability, CAD, safety*

## 1. Introduction

A forklift, also called as lift truck or counter-balanced truck is a powered industrial truck, which is used to lift, shift and move the material from one place to another place in an industry. Forklifts are primarily used for lifting and transferring heavy loads to stations or locations in warehouses, shops or construction sites. The earliest forklift truck was invented between 1914 and 1915 and put on the market since 1930s. After that, the increasing need of transporting military material during the World War II spurred the development of the Forklifts. Following the war, more efficient methods for storing products in warehouses were being implemented. Warehouses needed more maneuverable forklift trucks that could reach greater heights. More new forklift models were made that filled this need. Since then, forklift trucks have become indispensable equipment in manufacturing and warehousing operations. Forklifts can be electric powered or diesel powered. Electric forklifts are powered by stored batteries and require frequent charging to operate. These forklifts are best suited for indoor use in areas where ventilation is not great because they are quiet and do not exhaust. Electric forklifts have lower operating costs than diesel operated ones. However, their lifting capacity is limited to 3000 kg. Their batteries can take as long as 16 hours to charge and cool off, and have a slower acceleration than the trucks those run on diesel. Diesel powered forklifts are typically used outdoors due to exhaust gases. They cost less than electric forklifts to buy, but they have higher ongoing costs, as they need frequent refueling. Diesel-powered forklifts are typically capable of lifting weights ranging from 1000 kg to 25000 kg, which makes them ideal for heavy-industry situations and under in all types of weather. Usually a fully functional forklift would consist of the following major systems: the driving system, steering system, hydraulic system, lifting system, operator work area.

**Driving System:**

Like most of the trucks, one of the most important systems in a forklift is the driving system which allows the truck to move around. This movement is powered by a battery located in the back of the truck in case of electric forklifts and by diesel engines in diesel forklifts. All forklifts are front wheel driven. Driving system consists of Engine, clutch, transmission, drive axle, hub, wheel rim and wheels. In case of automatic transmission, there is an Automatic Torque Converter (ATC) provided which multiplies the engine torque and allow the truck to move on gradients with load. No clutch is required for the forklifts with ATC.

**Steering Mechanism**

The purpose of a steering mechanism is to point the vehicle in the right direction. It is achieved through gears, tie rods, cables and a series of linkages. Currently, most lift trucks are front-wheel driven and they use the rear wheels for steering. All of the weight (including battery) is placed on the drive axle for traction and braking action. When the truck turns, the rear end swings while the front end is stationary. The wheelbase of the truck also affects the steering: the shorter the wheelbase, the easier to turn .The steering system of a forklift consists of three major parts: a steering wheel connected to a steering box through a system of gears; linkages such as cables connecting the steering box to the front wheel assemblies; and front suspension parts such as tie rods which pivot the wheel assemblies.

**Hydraulic system-**

Hydraulic system is used in forklifts for three main purposes viz. lifting and lowering of the load, tilting of load and mast assembly, steering function. Two lift cylinders are provided for lifting a load to required height. Tilt cylinders are used for tilting load and mast assembly. Hydraulic steering provides feather touch steering and hence minimizes operator fatigue. Like normal vehicle, forklift also contains different parts as below, referring to fig1.

1 **Chassis-** Chassis of a forklift truck is the most important part. It the base part of a forklift truck and supports the structure. Drive axle, steer axle, mast, counterweight, engine and transmission and other forklift parts are assembled on forklift chassis. It also incorporates diesel tank and hydraulic fuel tank.

2 **Counterweight** - The load to be lifted is kept on forks which are at front side of the forklift. Due to this weight forklift may try to topple about the front wheels. To avoid toppling of the forklift some weight needs to be added at the backside of the forklift. This weight is called as Counterweight. Counterweight stabilizes the vehicle while travelling on plain ground as well as climbing the gradients.

3 **Drive train and wheels-** Drive train of a forklift truck consists of Engine, transmission, drive axle and wheels. Engine is mounted on chassis and it drives the automatic torque converter (ATC). ATC is used for

torque multiplication. ATC multiplies the torque according to user requirements. Then drive is transferred to transmission and drive axle and then wheels. Forklifts are front wheel driven vehicles.

4 **Steer axle and wheels-** Unlike in regular vehicle rear wheels are steered in forklifts. A double acting hydraulic cylinder is used to perform the steering operation. Steer axle is mounted on chassis. Steer wheels can either pneumatic or solid cushioned. Pneumatic tires are generally used for rough terrain forklifts such as forklifts used in mines while solid cushioned tires are used in forklifts which operates in warehouse.

5 **Mast** – The mast carries the load, which is to be moved or shifted. Mast consists of outer rail, inner rail, lift cylinders, and chain. Outer rail and inner rail are either I-section or Channel section. Inner rail slides vertically on the bearing mounted on outer rail there by providing required lifting height to the load. Single acting hydraulic lift cylinders are used for lifting inner rail against outer rail. This whole mast assembly is mounted on chassis.

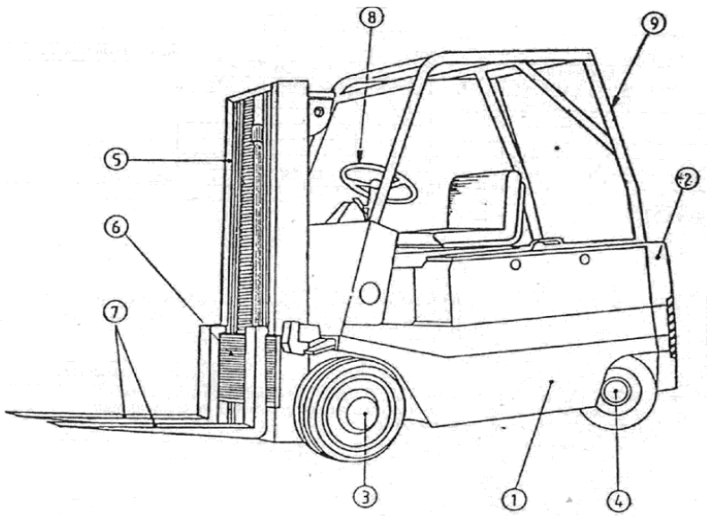


Fig.1 Introduction of forklift

6 **Carriage**- It is mounted on mast. It slides vertically up and down on bearings mounted on inner rail, in the same way as the inner rail slides in outer rail. The movement of carriage is carried out by chain.

7 **Forks** – Forks are mounted on carriage and travels with it. Load is placed on forks. Usually there are two forks in the front of a forklift that are used to lift loads that may weigh up to thousands of pounds.

8 **Steering wheel-** Steering wheel is like regular steering wheel used in commercial vehicles for steering purpose. In forklifts, steering function is carried out by hydraulic oil supplied by hydraulic pump. An orbitrol is connected to steering column which senses the steering wheel rotation and provides the required quantity of oil to steering cylinders. A priority valve is fitted inside the orbitrol which decides the priority between steering and lifting. Priority is always given to steering operation.

9 **Overhead guard-** It serves as a protection cover to operator. As the load is raised to higher heights, Overhead guard protects the driver from any accident. This part is usually a metal roof supported by posts at each corner of the cabin that protect the operator from any falling objects. It could be a separate assembly or in some forklifts, the overhead guard is an integrated part of the truck frame assembly.

**Important terms related to forklift**

Capacity : It is the maximum load truck can lift upto 3660 mm from ground at given load center.

Maximum fork height : Maximum fork height is the distance of the fork top face from the ground to which load can be lifted safely. It is briefly written as MFH.

Load center: It is the distance of the load CG from the fork face. Forklift is always specified by capacity and load center. For example- 4000 kg at 500mm load center.

Overall height lowered (OAHL): It is the measurement from the ground level to the top of the mast assembly when mast is fully closed. OAHL is required for finding out lowest height of door through which a forklift can pass.

Free lift : The distance of fork travel from ground level upwards before the inner channel starts to increase the height.

Full free lift (FFL): The forks can be raised till the height of mast without raising the inner channels. FFL is required when forklift is working in low ceiling area for stacking purposes like container stuffing and de-stuffing.

Overall height raised (OAHR): It is the maximum height achieved when mast is fully extended. It is also known as extended height. OAHR will be higher if load back rest is used as an optional attachment. OAHR is required to check for obstructions when mast is fully extended.

Minimum fork spread- : It is the minimum distance between outer edges of the forks.

Maximum fork spread-: It is the maximum distance between outer edges of the forks. This data is necessary to find out largest container a forklift can carry.

Turning radius-: Distance from Centre of turn point to the furthest away part of the truck body. It becomes important when turning area is very small.

## 2. Literature Review

IS4357:2004 standard specifies basic tests to verify the stability of the counter balanced trucks. This standard is applicable to all forklifts with tiltable and non tiltable mast of the rated capacity upto 50,000 kg. IS4357 specifies the tests to be carried out on manufactured forklift. The examination of the vehicle dynamics and stability of four-wheeled forklift trucks (FLTs) in cornering situations is done by Laboratoire in a paper-Dynamic stability of forklift trucks in cornering situations: parametrical analysis using a driving simulator Cornering at excessive speed is one major reason for fatal accidents with forklifts caused by lateral tip over. In order to increase the lateral stability of this kind of working machinery, the influence of certain important design properties has been studied using an appropriate vehicle simulation model and a driving simulator.

The articulated rear axle enables the truck to adjust to the ground's unevenness and to maintain a static stability. A special case when the swing angle is zero is also important, as movement of the rear axle may be blocked either accidentally or by a technical device aimed at increasing the truck's stability. The maximum value of the swing axle (preset by end-stop buffers) is not important, unless it is larger than the truck's actual roll angle. When the roll angle exceeds the swing angle, a lift-off of the inside rear wheel will occur, leading to an undesired instability of the truck. Multi-body simulation is known as a tool suitable for examining the driving dynamics of many kinds of vehicle. The underlying multi-body models are often used to set up driving simulators. Depending on the objective pursued, the model ought to have a suitable complexity. In this study, itwas shown that models consisting of just two bodies can adequately display the driving dynamics of four-wheeled FLTs with articulated rear axles. For four-wheeled FLTs without articulated rear axles or for three-wheeled FLTs, even single-mass models may be sufficient.

## 3. Tests

Following are the tests specified in is4357:2004:

1) Forward tip over stability while stacking

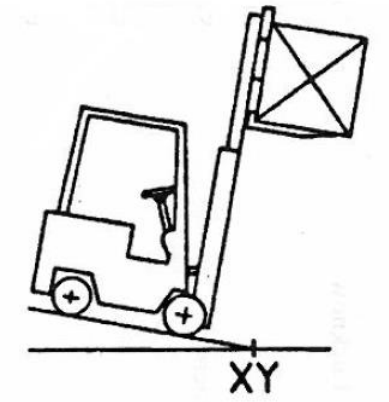


Fig1. Forward tip over stability while stacking

This test is carried out when mast is vertical and forks at maximum height, the maximum load is determined when the forklift is tilted forward on a platform to:

• A slope of 4% for forklifts of rated capacity up to 4999 kg; and

• A slope of 3.5% for forklifts with capacities of 5000 kg to 50000 kg

Often forklifts are used for lifting and placing the loads at higher heights such as 3000mm, 4000mm etc, hence this test considers the full MFH with which forklift can be operated, so that stability at higher heights can be assured. Fig.9 is the representation of the forklift position for this test. The actual test is performed by placing the forklift on tiltable platform. Then the platform is tilted slowly to said value i.e 4% and 3.5% for forklifts upto 4999kg and 50000 kg resp. The truck is considered stable if passes the test without overturning. Overturning is defined as the test platform slope value which, if increased, would cause overturning of the truck. It is required for the forklift not to skid and all the wheels should be in contact with the ground in the complete test.

2) Forward tip over stability while travelling

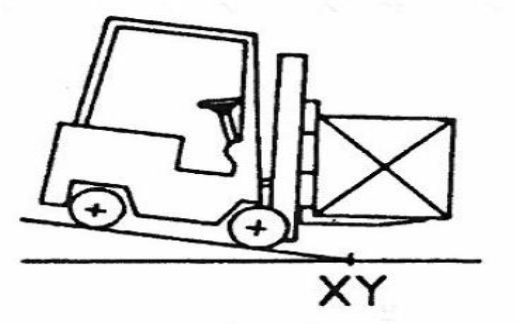


Fig2. Forward tip over stability while travelling

This test is carried out with the mast at full rearward tilt and forks lowered, the maximum load is determined when the forklift is tilted forward on a platform to a slope of 18%.

3) Side tip over stability when loaded

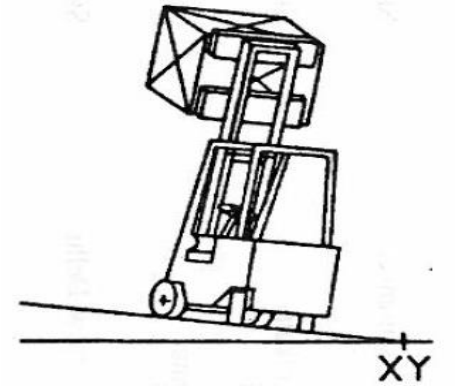


Fig.3 Side tip over stability when loaded

This test carried out with the mast at full rearward tilt and forks at maximum height, the maximum load is determined when the forklift is tilted sidewards on a platform to a slope of 6%

4) Side tip over stability when empty

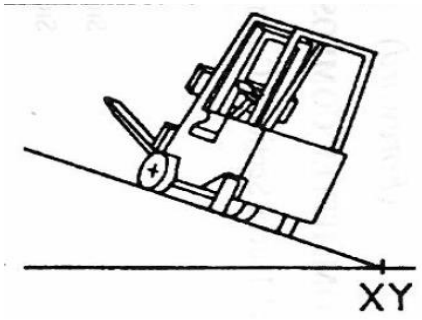


Fig.4. Side tip over stability when empty

This test is carried out with the mast at full rearward tilt and forks lowered, the forklift is tilted sideways on a platform to

• A slope of up to 40% for forklifts of rated capacity up to 4999 kg; and
• A slope of 50% for forklifts with capacities of 5000 kg to 50000 kg, depending on the forklift capacity and maximum speed. All above tests can be carried out in CAD.

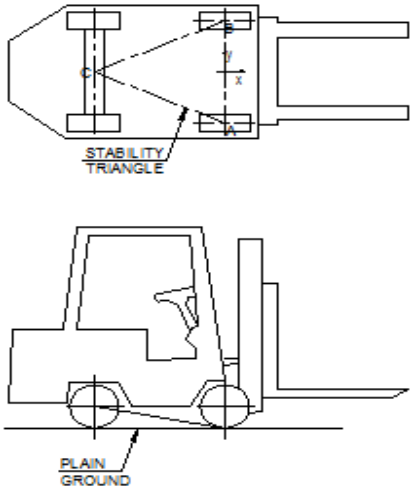


Fig.5

1) Stability Test-1

Condition-Mast vertical and full raised, with load

Measure the truck C.G from pivot in x and y direction as shown in fig.6

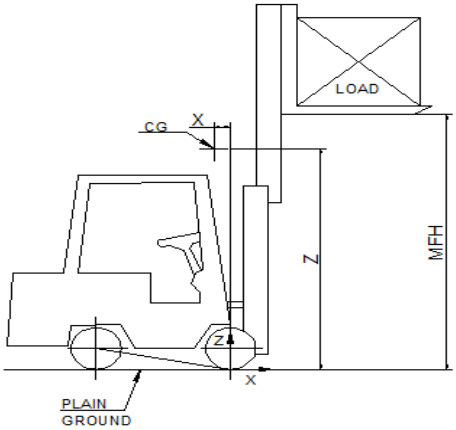


Fig.6

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For truck to be stable x/z >4%

2) Stability test-2

Condition-Mast tilted rearward and lowered, with load

Measure the truck C.G from pivot in x and y direction as shown in fig.7

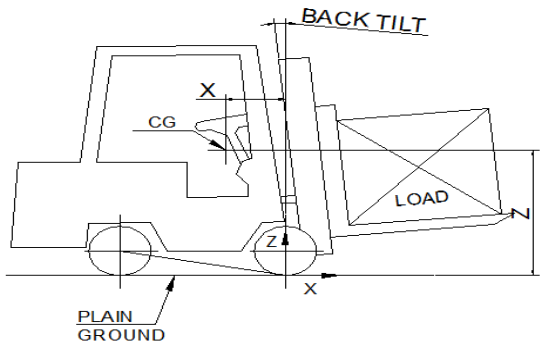
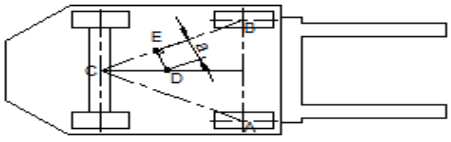



Fig.7

For truck to be stable x/y>18%

3) Stability test-3

Condition- Mast tilted rearward and raised to full height, with load



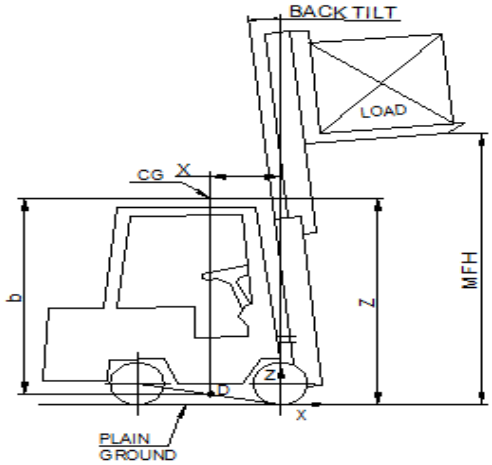



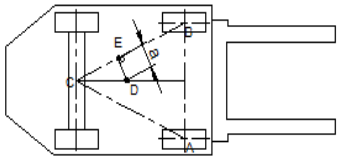

Fig.8

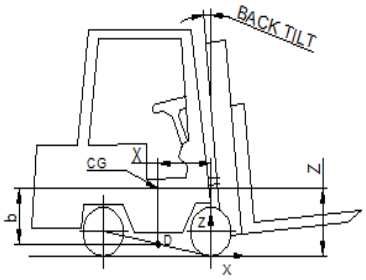
Mark a point of CG w.r.t to pivot.

Draw a vertical line from this point to the stability triangle. Mark this point as D. This will be length b.
From point D draw a line perpendicular to line joining rear wheel center and front wheel as shown in fig. Mark this point as E. This will be length a.
Now for a stable truck, a/b> 6%

4) Stability test-4

Condition- Mast tilted rearwards and forks lowered, No load on forks
Repeat procedure for test- for plotting points D and E.
As per IS4357:2004,
Slope=15+1.4V
Where, V= Velocity of truck in kmph
Now,
40%>a/b>slope for truck upto 4999kg capacity and
50% > a/b > slope for truck above 5000kg to 50000kg capacity.




## 4. Conclusion

By using CAD model of a forklift, it is possible to perform the stability tests mentioned in IS4357 in CAD itself. This can be done before actual manufacturing of the truck, so that further rework after manufacturing can be eliminated, hence rework cost and time can be saved. As the operation of forklift is full of risk, by ensuring the stability at the design stage, safety of operator and property can be assured.

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