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Design of Training Aid for Down the Hole Drilling Rig Equipment

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***Abstract*— Mechanical equipment training aids have been widely used in the last few years due to the fact that they allow mechanical equipment operators of all levels to acquire skills and experience for real in-field emergencies with comparatively lower cost. This paper presents the design of a training aid for the conventional down-the-hole drilling rig equipment [1]. The design and calculation reports, blueprints, and workshop drawings that result from work presented in this paper have been passed to a contractor to build the training aid. A comparison between the main technical specifications of both the original equipment and the implemented training aid is presented. The training aid has been implemented according to standards that govern building of light duty equipment considering safety precautions and providing all inspection and maintenance documents that assure safe operation as well as long service life. Considering the low cost training programs, the training aid has been tested and technically approved to be used for training the operators of the drilling rig equipment especially the beginner operators and those who are not yet qualified to operate the machine for not having enough in-field experience.**

Keywords— Construction Equipment; Hybrid systems; Reverse engineering; Terramechanics; Training programs.

I. INTRODUCTION

The need for construction equipment that is used for earthmoving, excavating, and lifting has grown with the size and complexity of construction projects in the last two centuries. Operation and basic principles for most types of construction equipment have not been basically changed since when they were evolved many years ago [2]. The use of training aids has recently emerged in the field of construction equipment to train operators from all levels. With proper-scaled prototype of real equipment, the operator is able to acquire the in-field work experience necessary for dealing with the emergency situations with a cost effective solution [3, 4].

Generally, the importance of the training aids for the development of working process can be summarized in the following: (1) optimum utilization of human resources, where training monitoring helps in planning for the task which leads to optimize the utilization of human resources to achieve the goals and accomplish the mission, (2) development of human resources, where practice helps to provide an opportunity and broad structure for the development of human resources' technical and behavioral skills in an organization, (3) development of skills of operators where experience helps in increasing the skills of operators at all levels [3, 4].

To mention the many advantages of using the one to one scale training aids in training programs, items like learning, practice and cost should be discussed. On the scale of beginners and considering learning how to drive an equipment, future operators training programs tend to get into cash problems as the cost of renting the equipment is high. With the training aid an operator can get an adequately practical learning program at a fraction of the cost [5, 6].

When it comes to practice the choice of using an affordable training aid makes more sense especially for such expensive machines. For advanced level operators and considering the development of their skills, nothing beats spending enough time of practice and experience in an environment looks like the real one. With the use of a training aid, operators are able to get more work hours and able to train in a wide variety of working environments without even leaving the training arena [5, 7]. Also an operator cannot be trained to be prepared for emergency situations in the field due to the risk involved so an indoor training aid is the closest way that can approach the real thing. By spending enough training hours using a realistic training aid, the equipment operators can learn how to handle dangerous situations so if a problem does happen they will know how to respond properly.

The key point of this paper is to present the design of a training aid, shown in Fig. 1 (left), to fulfill the requirements of the beginner operators training program for the conventional drilling rig equipment, shown in Fig. 1 (right). The main systems of the training aid are explained briefly in the next few sections of the paper as well as a comparison between the main technical specifications of both the original equipment and the implemented training aid.

Fig. 1. The training aid (left) vs. the original equipment (right)

II. DESIGN OF THE TRAINING AID

As the design and development of heavy construction equipment evolve from the needs of the users, heavy construction equipment manufacturers are very responsive to market needs and feedbacks. In fact if no equipment is available to perform a necessary task, it can be designed and built to fulfill the users' needs. However versatile Lattice boom crawler cranes that are equipped with augers for drilling holes are very common on most types of drilling hole operations, down-the-hole drilling rig equipment proves more efficient to do the job either for its high maneuverability especially when working in hard to reach places or for the devotion of many accessories that increase the equipment productivity when taking the time factor into consideration [2, 8, 9].

The drilling rig equipment is a mobile self-contained hydraulic crawlerd drill designed for blast-hole drilling in the mining, quarry and construction industries. The drill is equipped with a boom, drilling tool assembly, tool rack and a control panel. The conventional drilling rig is usually designed for drilling 89 to 105 mm diameter holes using drilling tools of diameters that begins at 76 mm diameter with depths up to 3.9 meters when equipped with 76 mm drill pipes.

To achieve the basic concept of developing a training aid that can be used in operators training program at a fraction of the cost, the design of the training aid, shown in Fig. 1 (left), is mainly based on reverse engineering of the construction of the original equipment [1], yet with lower specifications in features concerning the traction force, drilling power and the accessories. The training aid has been designed thoroughly according to the standard methods of design [10, 11] and taking into consideration the effect of the different Egyptian soil types on the tool [12, 13]. The detailed design of the training aid is considered out of the scope of this paper, and instead a brief explanation of the outcome product is presented in the following sections of the paper.

A. Power Calculations

To calculate the power needed to drive the drilling tool into rock, it can be simplified through taking into consideration the assumption of using rotary percussive drilling with drag drilling bit of diameter that varies from 0.075 to 0.15 m. The way the bit cut the soil depends mainly on the shape of the shear failure planes around the peripheral of the three tooth bit, as shown in Fig. 2. The forces resulted from the motor rotation can be assumed as linear forces around the drag bit peripheral each of which cut the soil at one of the bit cutting teeth, as shown in Fig. 2. These forces are calculated analytically using the soil cutting wedge illustrated in Fig. 3. The analytical mathematical model presented in Eq. (1)-(6) is used to predict the total soil resistance forces and therefore the total power required for drilling is calculated [12].

$$P = \left(\gamma g d^2 N_\gamma + cdN_c + c_a dN_{ca} + qdN_q + \gamma v^2 dN_a\right) \quad (1)$$

$$T_x = P\sin(\alpha+\delta) + F_{side}\cos\beta + F_{Fr}\cos\alpha + (W_b/g)a_h \quad (2)$$

$$T_z = W_b + P\cos(\alpha+\delta) + F_{side}\sin\beta - F_{Fr}\sin\alpha + (W_b/g)a_v \quad (3)$$

$$F_{side} = L_w\left(cd + \frac{d^2}{3}K_0\gamma w \tan\emptyset\right) + K_0 q d w \tan\emptyset \quad (4)$$

$$\sin\beta = \sqrt{\frac{\tan\emptyset - 2}{\cot(180-\alpha)(\tan\emptyset+2)}} \quad (5)$$

$$F_{Fr} = P\sin\delta \quad (6)$$

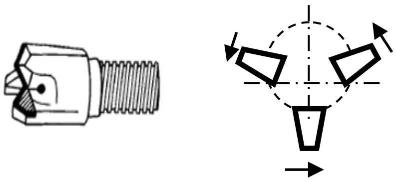

Fig. 2. Drag bit

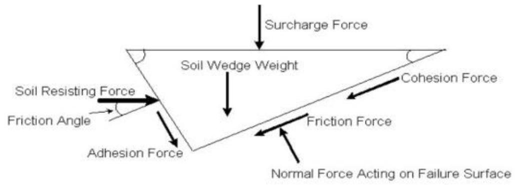

Fig. 3. Soil cutting wedge for a drag bit tooth [12]

III. COMPUTER MODELING AND DESIGN VERIFICATION

In this stage of the design procedures, it is important to make sure that the proposed design of different parts of the training aid, which is obtained using reverse engineering guided by the construction of the original equipment, is applicable. This assures whether both the training aid chassis as well as the working attachment can handle the expected stresses or not. Complete stress analysis for the machine chassis structure is performed using a computer model that has been developed for this purpose. The model, with all forces and constraints distributed on it, is used to calculate von mises stresses, first principal stresses and third principal stresses that influence the training aid main parts. The model shows that the main dangerous cross sections exist in the working attachment especially at the tool rack, which holds the drilling tool assembly. The model results for the main attachment tool rack, shown in Fig. 4 to Fig.11, assure acceptable values of safety factors and strains.

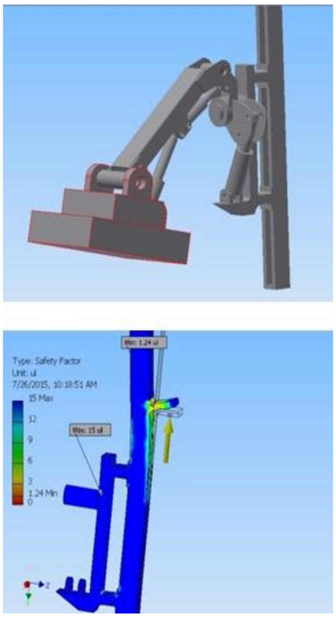

Fig. 4. Computer model of attachment (up) and safety factor results (down)

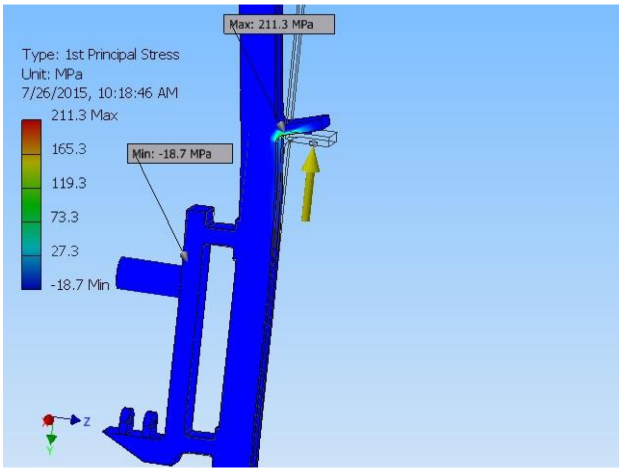

Fig. 5. First principal stress

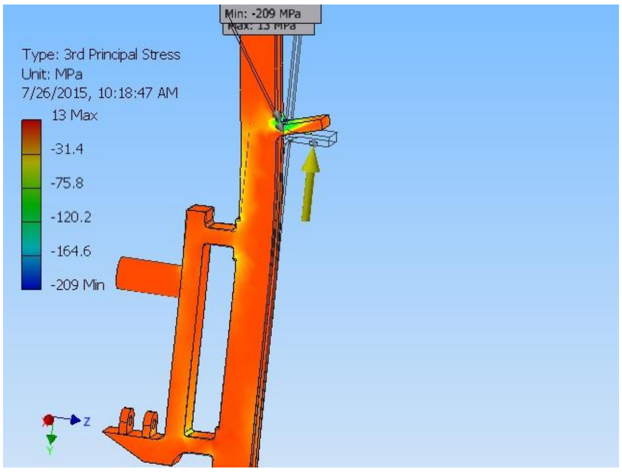

Fig. 6. Third principal stress

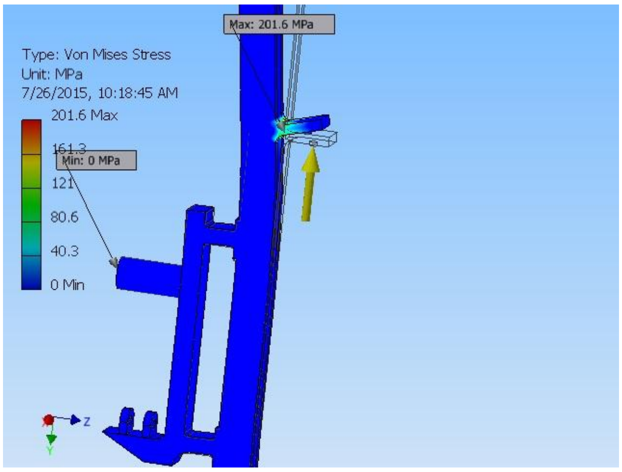

Fig. 7. Von misses stress

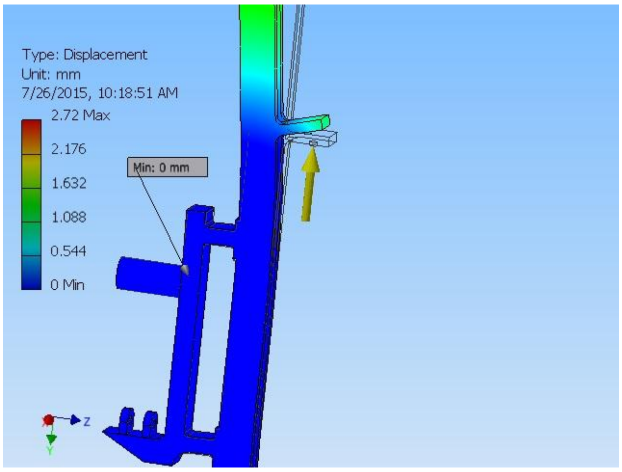

Fig. 8. Displacement

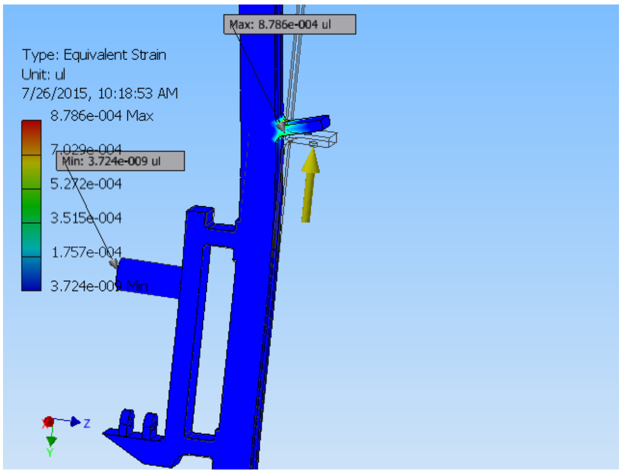

Fig. 9. Equivalent strain

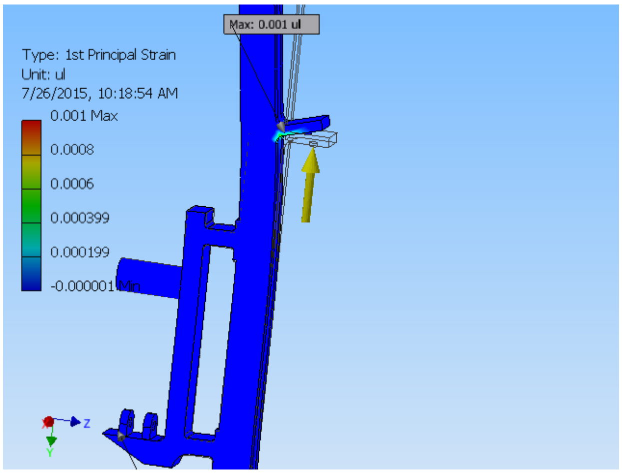

Fig. 10. First principal strain

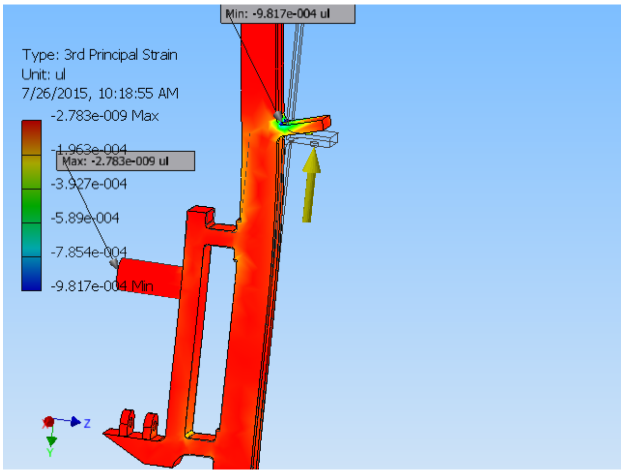

Fig. 11. Third principal strain

A. *Determenation of natural frequencies*

After using the computer model to develop a complete design of the training aid along with all blue prints prepared for the different parts of the equipment, the expected natural frequencies of the equipment should be determined to avoid resonance during operation. A realistic representation of the dynamics of drilling tool driving into the soil should consider the complex chain of events motivated by forcing the tool into the ground especially at the beginning of the operation.

The power delivered to the tool sets up time dependent stresses and displacements in the system that constitutes the tool, the tool fixation assembly, and the surrounding ground. Because the length of the drilling tool is always large compared to its diameter, the tool doesn't behave as a concentrated mass but more nearly as an elastic bar in which the stresses travel longitudinally as waves. When the waves are compressive, they cause the tool to penetrate into the ground as in the case of the tool being driven into hard soil. Yet, if the compressive stresses are great, they may damage the tool.

On the other hand, when the soil at the tool tip is soft and the tool penetration is easy, the compressive wave may be reflected upward from the end of the tool as a tensile wave [12].

Therefore the behaviour of the tool with respect to both its ability to penetrate into the soil and its structural integrity during the tool driving into the ground is intimately related to the mechanics of the stress-wave transmission within the tool. Thus the tool can be represented as number of unit masses attached to each other using springs of unit stiffness.

The integrity of the system modeling increases with the increase of the assumed number of masses. However assuming large number of masses would make the solution too complex to get. The tool is assumed here to be represented with four unit masses attached to each other using four springs each of which has unit stiffness. The natural frequency of the system is determined here using Holzer method [14] through plotting assumed operation frequencies (ω) as (0.2, 0.3, 0.4, 0.6, 0.8, 1, 1.5, 1.8, 2, 2.5, 3) rad/sec against calculated amplitude (*x*) of the fixed end of the tool at each operating frequency, the results are shown in Fig. 12. The natural frequency of the system is determined as the intersection of the curve with the frequency axis.

From Fig. 12, it can be seen that all natural frequencies of the machine during operation is lower than 3 rad/sec which is taken into consideration during the design of the tool speed control circuit. Again, the fact that the training aid is designed to fulfill a beginner operators training program requirements should be considered. The vibrations and shock mitigation mechanisms are not needed here as far as the training aid works at a fraction of power [15].

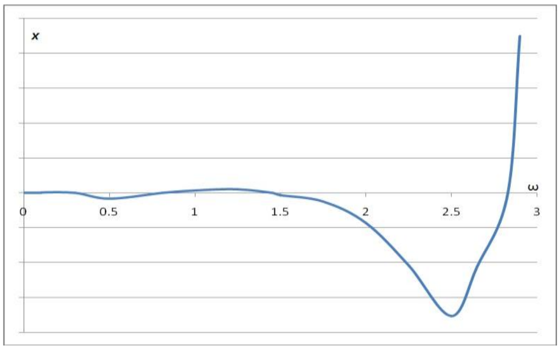

Fig. 12. Determination of natural frequencies of the system

The rotational speed of the driller should be increased as the type of soil is getting harder varying from clay to hard rock. To control the speed of the driller rotation DC motor, a PID controller is used. The controller can be tuned genetically to minimize the Mean Squared Error (MSE) between the reference input and the system's output as an objective function.

Also a position controller is designed for the DC motor of the driller feed. It is also a PID controller that can be tuned genetically to minimize the (MSE) between the reference input and the motor's output. The position is increased gradually in steps of order $\pi/4$ each of which corresponds to penetration depth of approximately 10 cm. The output response is chosen to be slow in order of 3 seconds so that the penetration depth can be achieved while the driller rotation speed is constant.

IV. DESIGN OF THE TRAINING AID MAIN GROUPS

In this stage, all design reports, blueprints, drawings and calculation reports developed from work presented in this paper have been passed to a contractor that is compliant to mechanical equipment manufacturers' regulations and requirements. The training aid has been built considering a dated working plan according to implements requirements criteria from [16-17]. The machine consists of five main groups which are the undercarriage, the superstructure, the cabinet, the main attachment, and auxiliary systems. Each group has been designed using rules of reverse engineering based on the construction of the original equipment taking into consideration the limitations of cost and target training program for beginner equipment operators.

A comparison between the main specifications of the training aid and that of the original equipment is mentioned in Table 1. The main dimensions of the training aid are much as the same as that of the original equipment. The only difference in dimensions between the two machines is that the boom of the training aid is shorter than that of the original equipment as it is not needed to drill holes of full scale depths during the training program. From Table 1, it can be concluded that the maintenance cost, operation cost and the power requirements of the training aid is much lower than that of the original equipment.

TABLE I. COMPARISON OF MAIN TECHNICAL SPECIFICATIONS

Specs.	Training aid	Orig. equip. [1]
Total height [mm]	5400	7200
Width [mm]	2160	2160
Total length [mm]	4850	4850
Track gauge [mm]	1850	1850
Track pl. width [mm]	310	310
Gr. cont. length [mm]	2150	2160
Gr. clearance [mm]	400	400
Main power	30 Kw DC Motor	Diesel Eng.
Max. tr. speed (km/hr)	10	20
Max. drilling sp. (rpm)	30	70
Fuel	Electric source	Diesel fuel
Engine Oils	-	Regular
Coolant	Air cooling	Water coolant
Drilling feed sp. (m/s)	0.4	0.8

A. *The undercarriage*

Guided by the construction of the original equipment, the undercarriage base of the training aid consists of a heavy-duty steel frame mounted on two track assemblies and a track oscillation shaft as shown in Fig. 13. The independently operated tracks are fitted with chain linked single bar grouser plates and equipped with chain guides. Track chains are kept tensioned by a hydraulic grease cylinder on the idler wheel. Each track sprocket is actuated by a hydraulic motor. The two hydraulic motors are equipped with 3-stage planetary gears in the hub of the sprocket achieving tractive force of about 58 kN on the first gear. An integrated, spring loaded, multiple disc safety brakes are used.

Fig. 13. The undercarriage

The traction forces required to drive the equipment is calculated using the traction theory for the gravelly sand [12], which is the most common type of soil in Egypt. The water-cooled, turbo charged, 4-cycle direct injection Deutz® diesel engine which is used in the original equipment is substituted with a three phase 30 Kw DC electric motor, which is used to operate the 120 bar hydraulic pump that is used to actuate the two hydraulic motors in the track through a parallel connection hydraulic circuit [18], as shown in Fig. 14. The DC motor is on/off controlled motor with emergency push button to switch off the motor in emergency cases. This design achieves low noise operation and offers long service intervals for efficient and environmental friendly use. The power train of the training aid is demonstrated in Fig. 15.

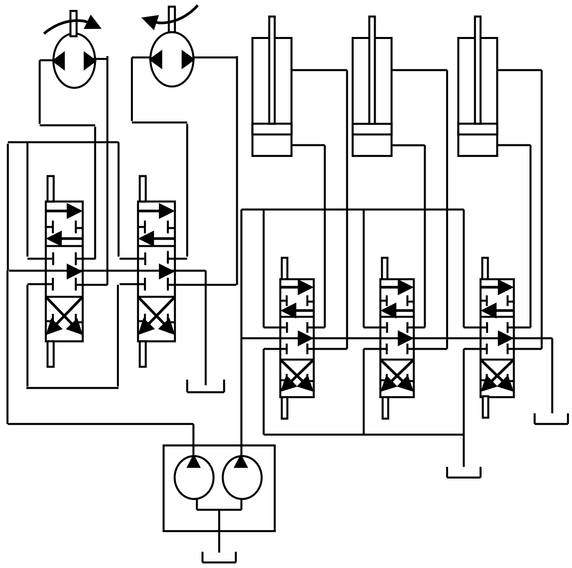

Fig. 14. Hydraulic circuit diagram of the training aid

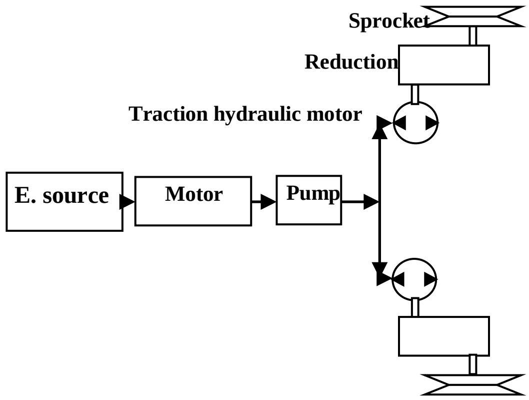

Fig. 15. The power train of the training aid

B. *The Superstructure*

The superstructure is generally composed of two main parts: (a) the cabinet (b) the tool rack and boom assemblies that are considered as the main attachments. Both parts will be discussed briefly in the following subsections.

C. *The Cabinet*

The cabinet of the drilling rig training aid from inside is a little bit different from the cabinet of the original equipment. The training aid is equipped with instruments that give the operator up-to-date information about the operation parameters to help him in his training program. The control panel indicators are provided with updated information from sensors which are attached to the actuators. The 24 V electric system features along with the electric control panel ensure updated monitoring for the main power source and drilling process. The drill is equipped with a reversing alarm and is fitted with two 12 V batteries. There are two safety-systems for emergencies: (1) emergency safety push button at the control panel to help the operator to shut down the system in case of emergency such as the existence of a human in the working zone of the equipment during operation, (2) emergency stop ripcord at the feed. The hydraulic system control levers are used to operate the hydraulic actuators and they are similar to the ones in the original equipment.

D. The Main Attachment

In the training aid, the boom is constructed from two parts that are bolted to assure durability and ease of maintenance. The boom is attached to the undercarriage in a way that allows it to move freely in a plane through three hydraulic cylinders to control angle of inclination of the tool rack assembly as well as its elevation, as shown in Fig. 16. The boom is built of square steel profile, which is fitted to the undercarriage with sliding ledges forming a fork type boom.

The role of the tool rack is to hold the drilling tool assembly which consists of the drilling tool and its driving DC motor which is attached to the rotation head cradle that moves linearly on the toothed tool rack using a DC motor through a chain. The drill feed is accomplished through a motor chain assembly and the motor rotation makes the cradle to slide on steel guides which reduce feed wear and maintain timing. However the rotation head in the real equipment is equipped with a 3-stage planetary gear and a hydraulic motor for attaining maximum torque, this system is not included in the training aid as it is not needed for training programs.

The 40 bar hydraulic gear pump is powered through the main motor integrated gearbox to actuate the boom three control hydraulic cylinders through a parallel connection hydraulic circuit shown in Fig. 14. Gear pumps are generally preferred because of their simple construction and easy maintenance with their low filtration requirements.

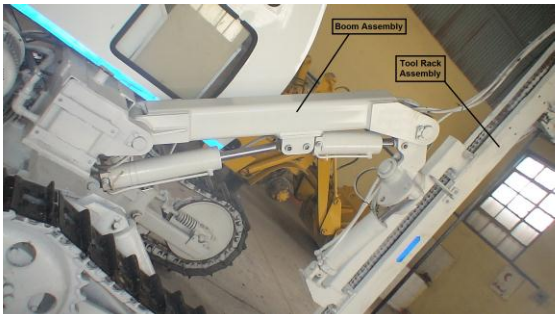

Fig. 16. The superstructure

E. Auxiliary systems and Accessorie

The original equipment is equipped with a combined cooler; one section is for engine coolant and the other for hydraulic oil. The design of the training aid cooler ensures that it is constructed of robust steel pipes to provide a large cooling surface efficient to do the job without any additional accessories as the training aid is not designed to operate in maximum power needed to drill productively in hard rocks.

Also, the auxiliary systems of the original equipment include a screw type air compressor, an air receiver, and a pneumatic control system of 12 bar operating pressure. The compressor unit comes with a standard compressor control operated by an ON/OFF switch, which can be adjusted to decrease the air volume and pressure for efficient drill hole collaring. Another auxiliary system the rig equipped with is an OE 200 lubrication device for flushing head, drill pipes and DTH hammer. Controls of the system are located on the operator's platform and can be controlled proportionally. The dry dust collector on the original equipment is equipped with a hydraulically driven suction fan. Some other optional accessories can be included in the original equipment such as; suction hood rubber, set of hose clamps, suction hose (to dust collector), air lock, hose clips, set of hoses, filter spanner, set of spray paints, fire extinguisher.

To achieve the cost effective design, some of the abovementioned accessories are not included. However many of them are taken into consideration to be included in the next development based on the evaluation results of the training program that can be linked to many factors two of which are the reality in training and safety procedures. Therefore, the inclusion of missing accessories can be seen as future work.

CONCLUSIONS

The construction industry will continue to use one-to-one scale training aids to help operators to get in-field experience at a fraction of the cost. This paper presents the design for a training aid of the conventional drilling rig equipment to fulfill the training program of the beginner operators to gain experience that is necessary to handle the real equipment and respond correctly in the case of emergency situations. The design of the main groups of the training aid has been explained briefly. Based on the design presented in this paper, the training aid has been built by a contractor. A brief comparison between the main technical specifications of both the original equipment and the implemented training aid is mentioned. Regarding the low cost training programs, the training aid has been technically approved to be used as a training aid for the operators of drilling rig especially the beginners.

NOMENCLATURE

P : Passive earth pressure force, N/m
T_x : Total cutting force in x direction, N
T_z : Total cutting force in z direction, N
F_{Fr} : Friction force, N
F_{side} : Side force, N
γ : Total soil density, kg/m^3
g : Acceleration due to gravity, 9.81 m/s^2
d : Total working depth below the soil surface, m
c : Soil cohesion, N/m^2
$C\ a$: Soil-metal adhesion, N/m^2
q : Vertically surcharge pressure. (per unit width)
v : Tool speed, m/s
w : Tool blade width
$N_{c,q,\gamma}$: Dimensionless factors of soil properties
N_{ca} : Soil-metal adhesion factor
N_a : an additional dimensionless factor comprised in soil cutting forces, which accounts for the acceleration forces in the soil with varying tool speeds, but a fixed soil strength
α : Rake angle
δ : Soil-metal friction angle
β : Failure plane angle of the soil wedge
T : Total cutting force, N
a_h : Blade acceleration in the horizontal direction
a_v : Blade acceleration in the vertical direction
W_2 : Weight of soil above rupture plane.
H : Horizontal reaction between

REFERENCES

[1] Down-the-hole Drilling Rig Manual Technical Specification.
[2] D. D. Gransberg, C. M. Popescu and R. C., Ryan, Construction equipment management for engineers, Estimators, and Owners, Taylor & Francis Group, USA, (2006).
[3] R. Zemke and T. Kramlinger, Figuring things out: a trainer's guide to needs and task analysis, MA: Addison-Wesley Publishing Company, (1982).
[4] J. A. Miller, and D. M. Osinski, Training needs assessment, SHRM.Paper,retrievedfrom:www.shrm.org/research/articles/articles/pages/CMS.000445.aspx,(1996).
[5] Y. Sakaida, D. Chugo, K. Kawabata, H. Kaetsu, and H. Asama, The analysis of excavator operation by skillful operator, in Proc. of 23rd International Symposium on Automation and Robotics in Construction, (2006), pp. 543–547.
[6] D. Schmidt, M. Proetzsch, and K. Berns, Simulation and control of an autonomous bucket excavator for landscaping tasks, In the IEEE International Conference on Robotics and Automation, ICRA2010, 5108:5113, (2010).
[7] W. McGehee, and P.W. Thayer, Training in business and industry, New York: Wiley, (1961).
[8] J. E. Russel, Construction equipment , Prentice Hall, (1987).
[9] F. Harris, Modern construction equipment and methods, Longman scientific & Technical, England, (1991).
[10] H. M. Mahgoub, Theory and design for mechanical equipment, Lecture notes, MTC, Cairo, Egypt (2013).
[11] J. F. Thorpe, Mechanical system components, Simon & Schuster, Massachusetts, USA, (1989).
[12] M. H. Mabrouk and M. E. Abo-Elnor, Terramechanics, P.G. Lecture Notes, MTC, Cairo, Egypt, (2014).
[13] H. Cannon, Extended earthmoving with an autonomous excavator, Master's thesis, Robotics Institute, Carnegie Mellon University, Pittsburgh, PA, May (1999).
[14] S. S. Rao, Mechanical vibration, 4th Ed., Prentice Hall. , (2004)
[15] J. Rajnauth and T. Jagai, Reduce torsional vibration and improve drilling operations, International Journal of Applied Science and Technology Vol. 2 No. 7; (2012).
[16] Structures and land Rig mobilization (ST) - stand-alone chapter of the IADC drilling manual, 12th Edition. Handbook guide by International Association of Drilling Contractors, 2015.
[17] IADC health, safety and environmental case guidelines for land drilling units. Handbook guide by International Association of Drilling Contractors, 2009.
[18] M. G. Rabie, Fluid power engineering, McGraw-Hill, USA, (2009).