Heavy Mass Energy Storage with Magnetic Levitated Wheels, Bearings and Locomotive

Daming Zhang
School of Electrical Engineering and Telecommunication
University of New South Wales
Australia, 2052
Email: daming.zhang@unsw.edu.au

***Abstract*— This paper presents a potential method to achieve grid-scale energy storage with a moderate efficiency. It is based on heavy mass potential energy conversion into and from electricity by moving the containers with heavy masses between a high platform and a low platform. A locomotive either conventional one or magnetic levitated one is positioned at the top platform and moves along its track. Containers' holder is guided by four vertical support poles and moves along them. A metallic chain-type belt is adopted to connect the base of the containers' holder with the locomotive. At the belt turning point located at the top of the passage and close to the high platform, multiple distributed wheels with mounted permanent magnets are adopted to reduce the force acting on each wheel. Horizontal belt guide is also designed to reduce mechanic vibration. Furthermore shared container covers are adopted to reduce the cost of the system.**

***Keywords*— Energy storage; magnetic levitation; heavy mass; locomotive; vertical movement**

I. INTRODUCTION

Cost effective and environment-friendly grid-scale energy storage with relatively high efficiency can pave the way to ultimately solve energy crisis faced by human-beings [1]. New generation of nuclear fission is one solution. Nevertheless such solution leads to headache caused by slowly decaying and radiating nuclear waste. Before nuclear fusion based generation comes into being, it is good to find other better solutions. So far some efforts on using heavy mass energy storage have been put by different groups of researchers. In the design given in [2-4], the friction leads to low efficiency, thereby making the design less attractive. In [5-7], friction issue was reduced significantly. Nevertheless there is a significant use of magnetic steel which may present a problem.

In this paper, a new design of using heavy mass energy storage is proposed which has the following features 1) less use of magnetic steel; 2) reduced cost on the containers etc. Nevertheless such new system is only a complement to the design in [5-7] which presents higher efficiency.

The following contents are arranged as follows. In Section II, description on the new system is presented; Section III shows a simplified method to calculate the magnetic levitation force; Section IV presents a new design of the shared container support to reduce overall cost of the system; Section V concludes this paper.

II. DESCRIPTION ON THE SYSTEM

Figure 1 shows the diagram of forces acting on the belt and on the magnetic levitated wheel. Under steady-state movement, the dragging force provided by the locomotive is the same as the weight of the uplifted system, which includes the containers with heavy masses, part or complete of the chain-type belt and the containers' holder.

To reduce the friction losses in the wheel, it is necessary to produce sufficient levitation force, which is calculated by the following expression:

$$F_r = 2F\cos\alpha = 2F \times \cos\left(\frac{180^0-\theta}{2}\right) = 2F\cdot\sin(\theta/2) \quad (1)$$

Then the required magnetic levitation force divided by weight of the uplifted system is given by

$$Factor = \frac{F_r}{F} = 2\sin(\theta/2) \quad (2)$$

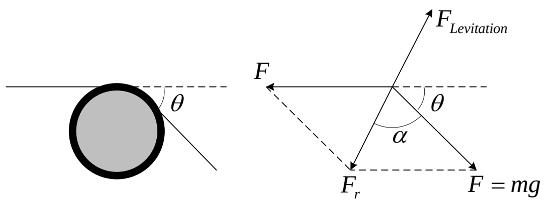


Fig. 1. Force diagram

TABLE I. FACTOR AND WHEEL NUMBER AGAINST ANGLE

Angle θ	Factor by (2)	Number of wheels
5^0	0.0872	18
6^0	0.1047	15
9^0	0.1569	10
10^0	0.1743	9
15^0	0.2611	6
30^0	0.5176	3
45^0	0.7654	2
90^0	1.4142	1

When only one wheel is used, the required lifting force is high. Therefore multiple wheels need be adopted to share the total lifting force.

Table I shows 1) the ratio of the levitation force to the weight of the uplifted system and corresponding number of wheels with different angle θ as indicated in Fig. 1. Such relationship is also shown graphically in Fig. 2; 2) the required number of wheels for each angle θ. From Table 1 one can see that the required magnetic levitation force by each wheel is around 10% weight of the uplifted system if 15 wheels are used.

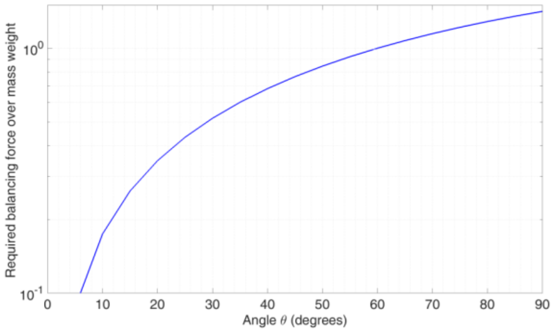


Fig. 2. Ratio of the levitation force to weight of the uplifted system versus angle θ

A brief sketch of the overall systems is shown in Fig. 3 and Fig. 4. In Fig. 3, there are two magnetic levitated bearings, each of which is the one as shown in Figs. 5a through 5c. In Fig. 4, there are three magnetic levitated bearings, each of which is the one as shown in Figs. 5a through 5c.

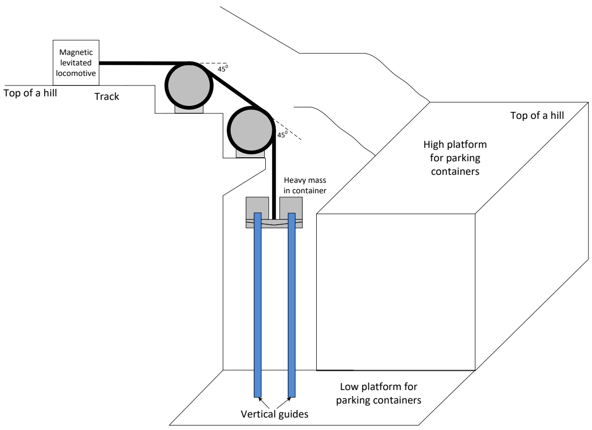


Fig. 3. Overall system with two wheels

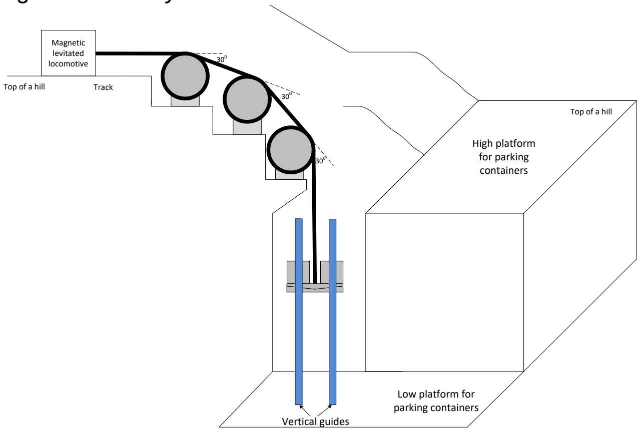
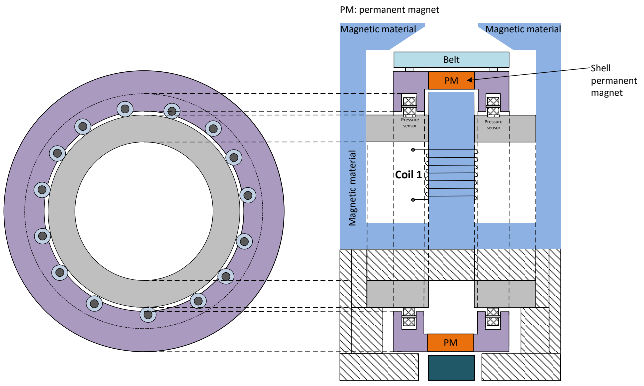


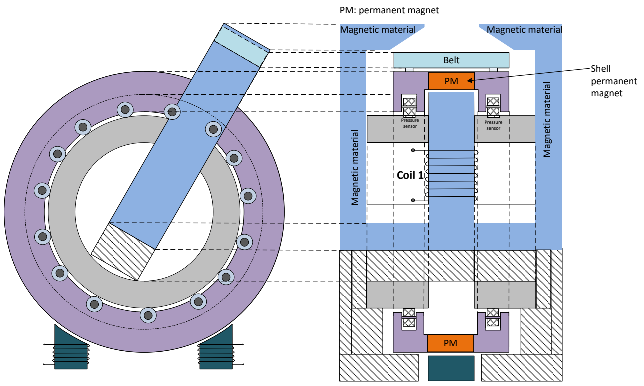
Fig. 4. Overall system with three wheels

The magnetic levitated locomotive can be the same as that of magnetic levitation train (MagLev). When the container holder with/without containers moves from the low platform to high platform, it works in the motoring mode while when the container holder with/without containers moves from the high platform to low platform, it works in the generation mode. Power is exchanged between locomotive and power grid. To save cost, conventional machine without magnetic levitation track could be used if efficiency is not an issue.

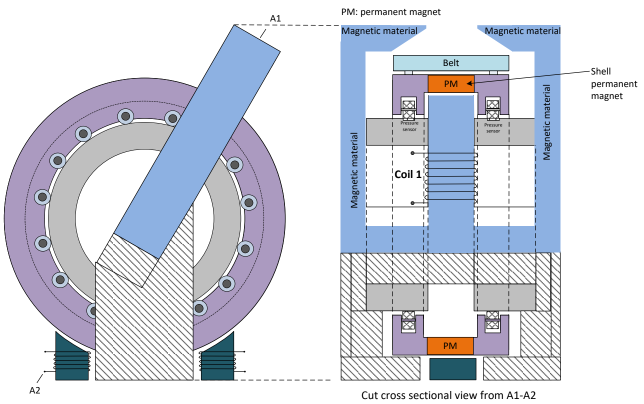
The magnetic levitation needs to produce sufficient force which makes the press force close to zero on the pressure sensor as shown in Fig. 5a through Fig. 5c. To reduce the frictions when the shell with permanent magnets rotates, one may use another pair of coils as shown in Figs. 5b and 5c to produce the lifting force to counterbalance the weight of the shell with permanent magnet.



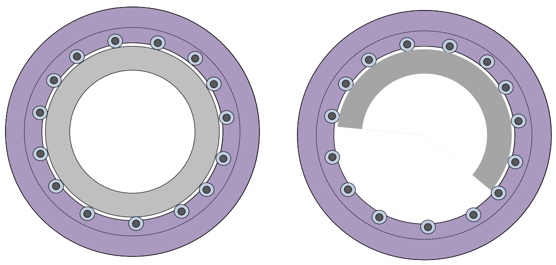
(a)



(b)



(c)

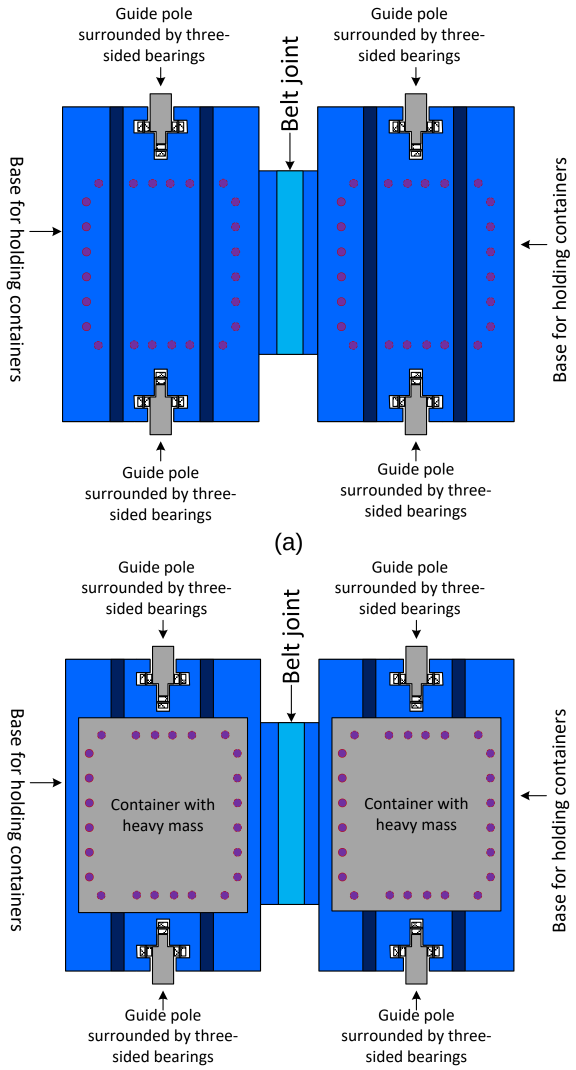


(d)

Fig. 5 (a) Drawing 1; (b) Drawing 2; (c) Drawing 3; (d) Support for shell with mounted permanent magnet

Instead of using a complete shell structure to support the shell with mounted permanent magnet, one may use more-than-half semicircular shell as shown in Fig. 5d to reduce the rotational friction.

Figure 6 shows horizontal cross section view of a possible design of the containers' base guided by four vertical poles spreading from low platform to high platform. Three-sided bearings are mounted on the containers' base. Two identical containers sit symmetrically on the base, with which chain-type belt is joined.



(b)

Fig. 6. Pole guided container base where containers sit (a) without containers; (b) with containers

Solid guides for the chain-type belt and containers with heavy masses are necessary for vertical movement of the belt in order to reduce the vibration which may lead to reduced efficiency. Horizontal solid guide with grounded support for the belt is also necessary.

Figure 7 illustrates a possible design for horizontal belt guides along the locomotive tracks, where bearing guides are suspended by horizontal bars which are supported by vertical poles along the sides of the locomotive track. All the bearing guides with their supports are connected through soft ribbon belt and driven by the locomotive.

Figures 8a shows another possible design for the horizontal belt guides, where stationary supports are connected with grounded support as shown in Fig. 8b. The chain-type multiple-unit belts are held by suspending rods with bearings at the top through hooks, and the bearings are placed inside the stationary support, along which the bearings move together with the locomotive and the belt.

When the system works in the mode of lifting-up container holder with/without containers, each unit of the belt is lifted up and hooked by the suspense rod and moves together with belt and locomotive. When the system works in the mode of lowering down the container holder with/without containers, each unit of the belt is driven by the container base and moves down to the vertical passage after being de-hooked from the suspense rods.

III. MAGNETIC LEVITATION FORCE

Figure 9a is a simplified model used to calculate the magnetic levitation force acting on the permanent magnet mounted on each wheel, which is approximately expressed as follows,

$$F_{levitate} = \int \frac{B_1(z) \cdot B_2(z)}{2\mu_0} dS = \frac{B_1 \cdot B_2}{2\mu_0} \cdot \left(L_{pm} \cdot W_{pm}\right) \quad (3)$$

where B_1 is the flux density on the surface of the permanent magnet produced by the current-carrying coil 1 in Fig. 5 and B_2 is the flux density on the surface of the permanent magnet.

In one design, $\theta = 9^0$ and ten wheels are used.

If the total weight of one container is 20 ton and two containers are 40 ton, then each wheel needs to provide a levitation force of 0.1569*40=6.276 ton.

Assume B_1=0.9T, B_2=0.8T. Then the required $L_{pm} \cdot W_{pm} = 6.276 \times 1000 \times 9.81 \times 2 \times 4\pi \times 10^{-7} / (0.9 \times 0.8)$ $=0.2149m^2$.

If L_{pm}=1.0m, then W_{pm}=0.21494m. The radius of each wheel is determined by

$$r = \frac{W_{pm}}{\theta} = \frac{0.2149}{9^0 \times \pi / 180^0} = 1.368\text{m} \quad (4)$$

Assume that the total air-gap of the magnetic loop is 0.3m. Then the required ampere-turns are

$$Ni = \varphi \cdot \Re = \frac{B_1 l}{\mu_0} = \frac{0.9 \times 0.30}{4\pi \times 10^{-7}} = 2.1486 \times 10^5 \qquad (5)$$

If the current flowing through the coil is 50A, then the required turns are approximately 4297.

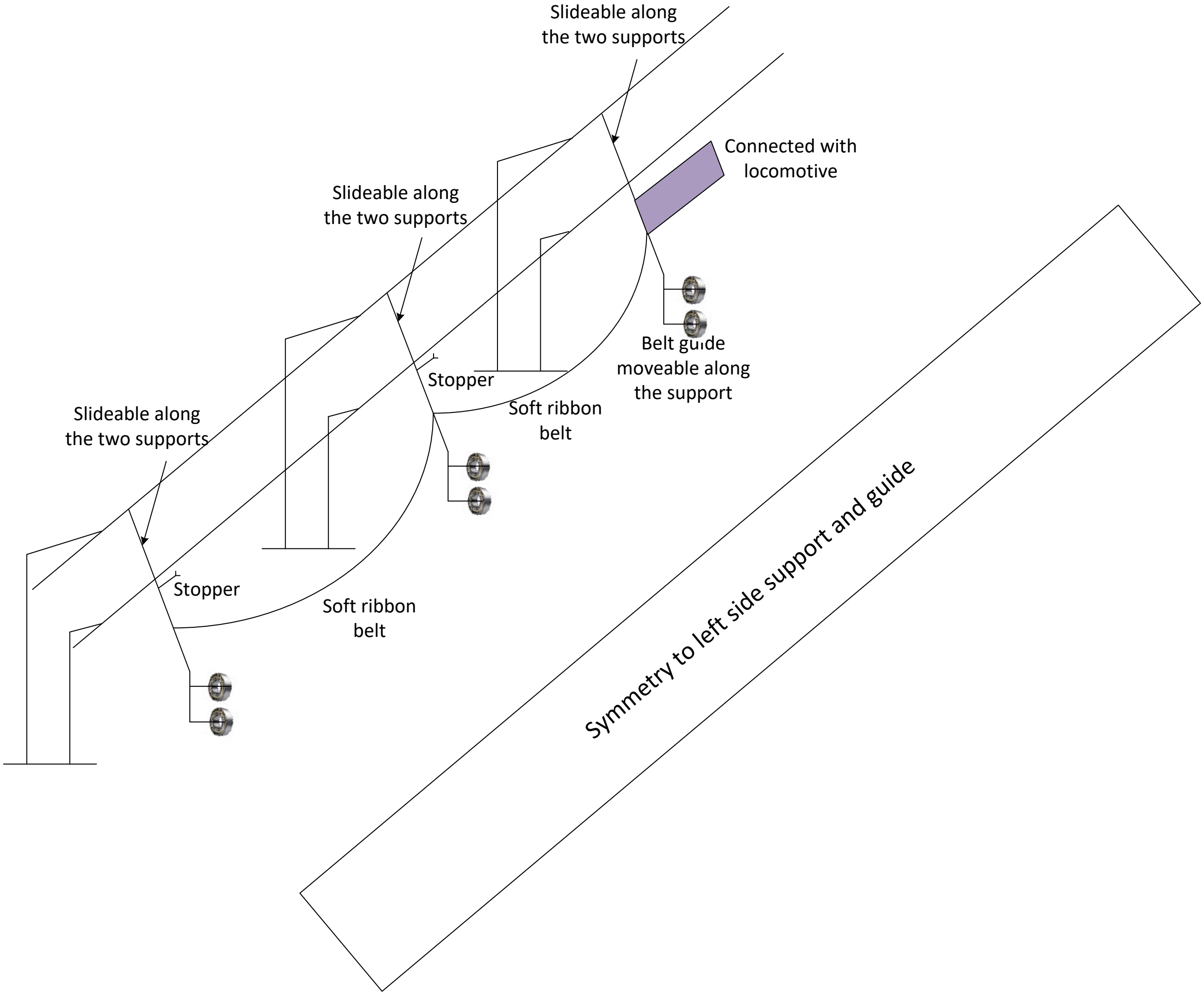


Fig. 7. Configuration 1 of horizontal guides for belt

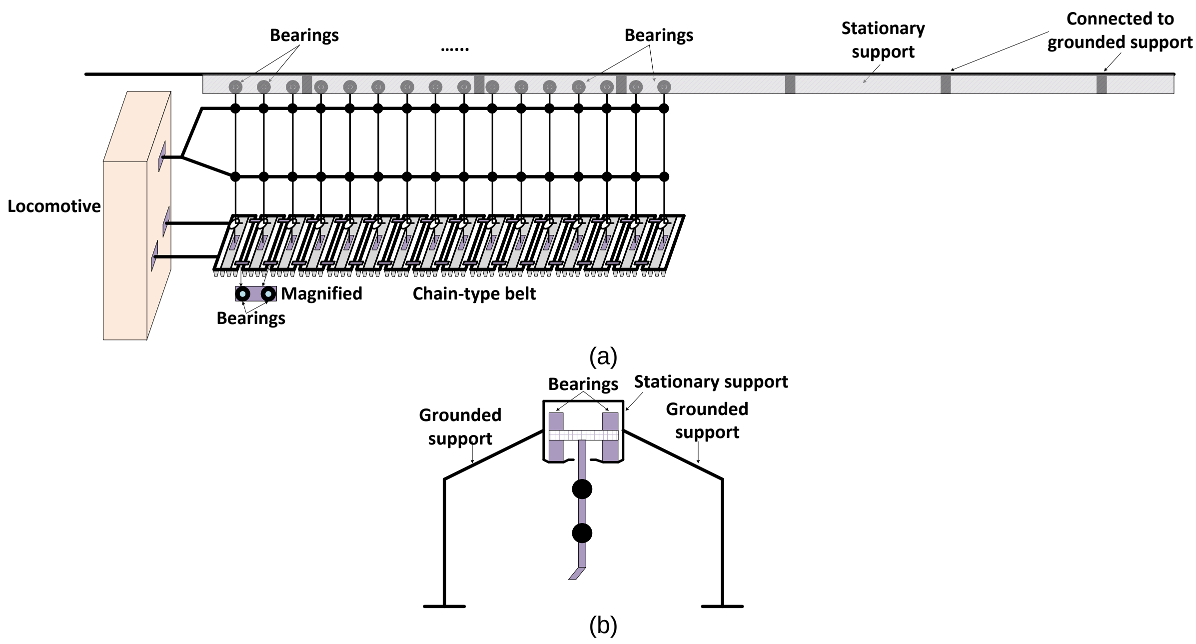


Fig. 8. Configuration 2 of horizontal guides for belt

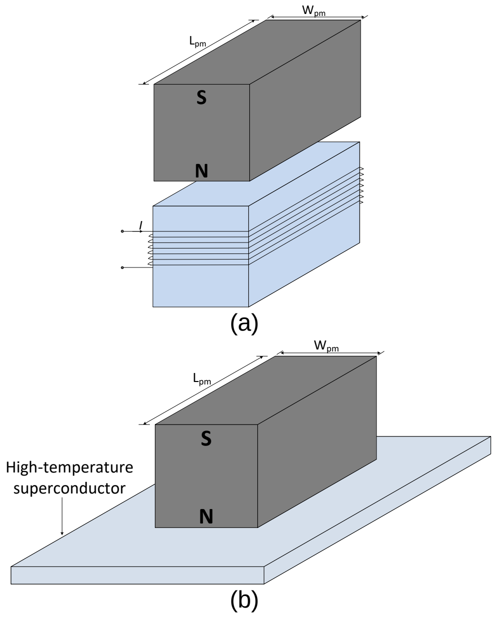


Fig. 9. Simplified model for magnetic levitation force calculation

Instead of using conventional windings wound on the magnetic core to produce repulsive magnetic levitation force, one may use high-temperature superconductor as shown in Fig. 9b to produce the levitation force. In such structure, the repulsive force density is

$$P_{Levitate} = \frac{B^2}{2\mu_0} \quad (6)$$

IV. SHARED CONTAINER SUPPORT

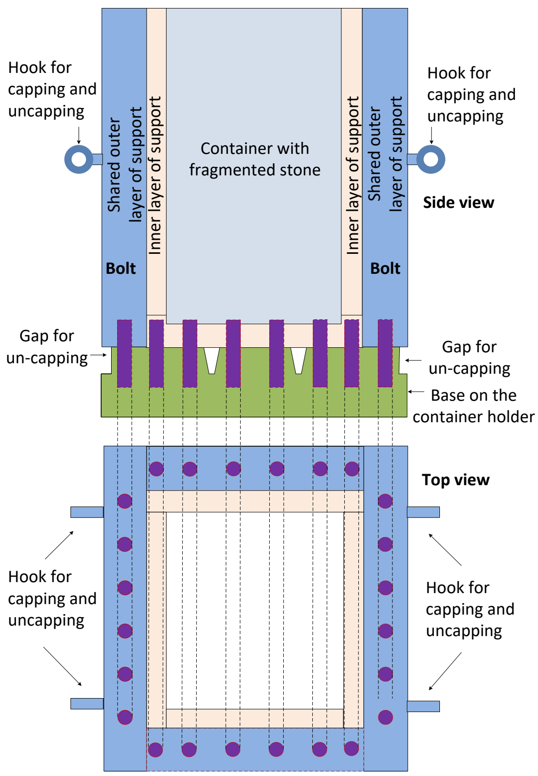


Fig. 10. Containers sitting on the container holder or base as shown in Fig. 6

The affordable heavy mass could be fragmented stones. To reduce the cost further, each container needs to have minimum stainless steel support or other reinforcement. To achieve such purpose, one may use shared supports made of stainless steel or other materials in the shape shown in Fig. 10. Such support is four-sided, leaving bottom side facing down with protruding bolts to be coupled with the holes on the base of the container holder and leaving top side being empty as shown in the figure. The four-sided cover can be removed from the container. One may produce multiple such covers which are shared among containers to save time taken to cover and uncover it over the container. When the containers reach destination on either top or bottom parking platform, the cover is removed and container with inner layer support joins in queue with others and supported by container stoppers whose top view is shown in Fig. 11, where there are two rows of the containers sitting on the tracks, each row containing three containers with heavy masses. The whole parking platforms are formed by multiple units as shown in Fig. 11.

To make it easier to cover and uncover over the container, one may use three joined sides plus one disassemble-able side to replace the design in Fig. 10.

The container and its cover in Fig. 10, and parking arrangement in Fig. 11 are also suitable to those designs in [5-7].

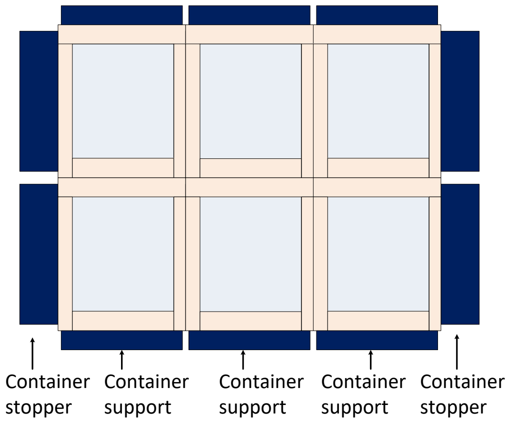


Fig. 11. Parked containers with heavy mass supported by the side support and back/front stopper

V. CONCLUSION

This paper presents a potentially useful grid-scale massive energy storage using potential energy in the heavy masses, in which there are high and low platforms. At the high platform sits the locomotive on its track, either conventional or magnetic levitated one. Containers' holder is guided by four vertical poles along which the holder with/without containers moves vertically. Metallic belt joins the containers' holder with the locomotive. At the belt turning point located at the top of the passage and close to the high platform, a distributed multiple wheel system is adopted to share the required lifting force, each of which only takes a small fraction of the total force. Furthermore magnetic levitation is adopted by mounting the permanent magnet on each wheel, interacting with the magnetic field producing by the current flowing through a coil wound around magnetic materials, part of a magnetic loop. A shared container reinforcement for increasing mechanic strength is proposed to reduce overall cost of the system, making it potentially economical to implement such design.

ACKNOWLEDGEMENT

This is to acknowledge the positive support from my colleagues.

REFERENCES

[1] Alan J. SANGSTER, “Massive energy storage systems enable secure electricity supply from renewables”, J. Mod. Power Syst. Clean Energy (2016) 4(4):659–667.

[2] UWilliam R. Peitzke, TMatthew B. Brown, William L. Erdman, Robert T. Scott, William H. Moorhead, Douglas C. Blodgett, David I. Scott, Utility Scale Electric Energy Storage System, USA patent, No.: US 8,593,012 B2.

[3] Daniel N. Boone, ENERGY WEIGHT STORAGE, USA patent, No.: US 2016/0138572 A1.

[4] Tom Scott, ViewTekz LLC., “ENERGY STORAGE”, USA patent, US 7,973,420 B2.

[5] Daming Zhang, “Issues on Series-Parallel Circuits and their Drives in the Linear Machine for Heavy Mass Energy Storage System”, ACPEE, Hangzhou, China, pp. 1-11, March 2019.

[6] Daming Zhang, “A Massive Energy Storage System with distributed rotor or mover structure and transitional pulse current”, USA patent, filed in March 2019.

[7] Daming Zhang, Journal of Multidisciplinary Engineering Science and Technology, on-line link: http://www.jmest.org/vol-6-issue-1-january-2019/, pp. 9361-9371, 2019.