반도체 스위칭 소자를 이용한 임펄스 착자기의 비용 산정 및 경제성 분석

(Cost Estimation and Economical Efficiency Analysis of Impulse Magnetizer using Semiconductor Switching Device)

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요 약

반도체 스위칭 소자를 이용한 커패시터 방전 임펄스 착자기는 착자요크에 순간적인 고전류 임펄스를 방전시켜 여러 종류의 영구자석을 생산하는데 사용된다. 요즈음 이러한 착자기의 비용은 상당히 고가이다.

본 연구에서는 반도체 스위칭 소자를 이용한 커패시터 방전 임펄스 착자기의 비용산정을 위한 방법 및 그 경제성 분석에 대하여 제시하였다. 이를 위하여 5개의 부시스템으로 구성되는 비용 구조를 이용하였다. 특히 Learning Curve를 이용한 임펄스 착자기의 비용감소 및 평가절하에 의한 비용의 변동추이를 관찰하였다. 중용량 착자기와 연결된 철심요크 (브러시레스 직류모터의 8극 회전자 자석용)를 이용하여 신뢰할 수 있는 결과를 얻었다.

Abstract

A capacitor discharge impulse magnetizer using semiconductor switching device is used to produce a high current impulse of short duration in a magnetizing fixture for magnets of the various shapes. The price of today's magnetizer is relatively expensive.

This paper described a method for cost estimation of capacitor discharge impulse magnetizer using semiconductor switching device and the economical efficiency analysis. We used a cost structure consisted of five major subsystems. Especially, we estimated the potential for a cost reductions in impulse magnetizer as a function of time using the learning curve, and the potentials of cost by depreciation. The reliable results were obtained by using iron-core fixture coupled to a middle-voltage magnetizer.

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1. Introduction

Capacitor discharge impulse magnetizer using semiconductor switching device has been under development for magnetic applications. The required magnetic pole pattern is produced by placing the magnet in wire-wound fixture and discharging a large capacitor bank through the fixture.[1-7] The price of this magnetizer is relatively expensive for industrial applications. The objective of this study was to evaluate the possible cost reductions of capacitor discharge impulse magnetizer for industrial aspects. A major part of the effort was to estimate the cost and the physical dimensions of these impulse magnetizers. We made costs estimates based on today's technology and projected how the costs might be reduced due to increased production cost savings (i.e., learning curve effects) or increased competition[8-12] and we estimated the potentials of the cost by depreciation.[13] Also, today's costs and projections at one, three, five and ten years were calculated, as discussed later. The cost reduction guidelines presented in this paper are general in nature, and may be applied to any type or size system through small transformation regardless of the driven magnetizing fixture. Examples used are middle-voltage magnetizer and 8-pole magnetizing fixture in industrial applications, but the economic tools are also applicable for commercial applications.

2. Capacitor discharge impulse magnetizer

The circuit shown in Fig.1 is a capacitor discharge impulse magnetizer using semiconductor switching device.[3] Since a typical magnetizing fixture is essentially a fixed configuration of wire loops, its impedance can be modeled as a series R-L circuit shown in Fig.1. The rectified power supply providing the initial charge for C and the gate triggers for the SCRs are not shown in the Fig.1.

Initially, the capacitor C is charged with the polarity indicated in Fig.1 and SCR1 is off. In order to transfer the energy from the capacitor C to the R-L load (equivalent circuits of magnetizing fixture), SCR2 must be turned on. Therefore, the recovery diode D prevents the capacitor voltage from dropping below about 0[V]. Capacitor C is recharged through SCR1 to its original voltage and polarity. The firing of SCR2 delivers the load impulse again and the whole cycle is repeated.

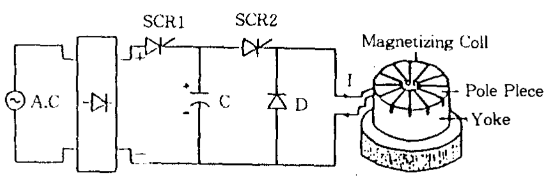


Fig. 1. Capacitor discharge impulse magnetizer using semiconductor switching device

3. Cost modeling

Economic evaluation is a useful tool to determine the relative merit of system proposals with different characteristics. The results of the evaluation help the user to choose the alternative that is most profitable for the business.

We used the cost structure that consisted of five major subsystem: 1)capacitor bank, 2)step-up transformer, 3)semiconductor devices (SCR1, SCR2, freewheeling diode, bridge diode), 4)magnetizing fixture, 5)related electronic circuits.

3.1 Capacitor bank

The cost of the capacitor bank is based on the energy of capacitor.

$$C_c = E_c \cdot U_c \qquad (1)$$

where C_c = total cost of capacitor [$]

E_c = energy of capacitor [J]

U_c = unit cost of capacitor [$ /J]

The energy of capacitor EC is expressed as a capacitance, C[F], of the capacitor voltage, V [V].

$$E_c = \frac{1}{2} \cdot C \cdot V^2 [J] \qquad (2)$$

3.2 Step-up transformer

The cost of the step-up transformer is proportional to the electric power requirement of the transformer, PT[VA].

$$C_T = P_T \cdot U_T \qquad (3)$$

where C_T = total cost of transformer [$]

P_T = electric power requirement of transformer [VA]

U_T = unit cost of transformer [$ /VA]

The transformer power is estimated from

$$P_T = P_L / (\eta_T / 100) \qquad (4)$$

where P_L = apparent of the load [VA]

η_T = transformer efficiency [%]

Generally, the efficiency of the transformer is about 98.5[%], assuming a small transformer.

3.3 Semiconductor devices

The semiconductor devices consists of SCR1 for charging switch of capacitor bank, SCR2 for discharging switch of capacitor bank, freewheeling diode D for circulating currrent of load, and bridge diode for convert AC to DC. The cost of the semiconductor devices are based on the power ratings according to the number of various devices.

$$C_s = P_s \cdot U_s \qquad (5)$$

where C_s = total cost of semiconductor devices [$]

P_s = electric power capability of semiconductor devices [VA]

U_s = unit cost of semiconductor devices [$ /VA]

3.4 Magnetizing fixture

The magnetizing fixture includes the winding coil, and the steel structure for magnetic path. Therefore, the cost of the magnetizing fixture are based on the manufacturing cost of magnetizing fixture with yoke shapes and the mass of the steel and the wire.

$$C_F = P_F + M_{st} \cdot U_{st} + M_{co} \cdot U_{co} \qquad (6)$$

where C_F = total cost of magnetizing fixture [$]

P_F = manufacturing cost of magnetizing fixture with yoke shapes [$]

M_{st} = mass of steel [kg]

U_{st} = unit cost of steel [$ /kg]

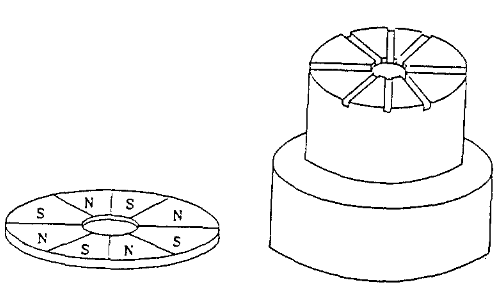
M_{co} = mass of copper [kg]

U_{co} = unit cost of copper [$ /kg]

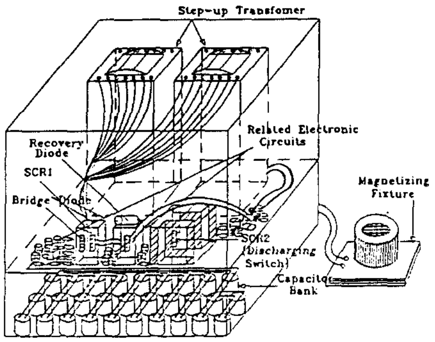
Among the above three components, the magnetizing fixture is dominated by the manufacturing cost of fixture with yoke shapes.

3.5 Related electronic circuits

The related electronic circuits consists of gate driver circuits for SCR, heat sink for sinking of SCR, and stabilizing system for stability of capacitor charging, et al. The cost of the related electronic circuits are almost contant because the circuits are control equipment. In this case, the cost of related electronic circuits is about 200~375 [$], assuming a related system. These costs are



(a) 8-pole magnetizing fixture



(b) capacitor discharge impulse magnetizer

Fig. 2. 8-pole magnetizing fixture and impulse magnetizer

based on discussions with conventional users. Support components were not included in the cost estimate.

4. Cost estimation results

4.1 Application case studies

As a application case studies for cost estimation consider a middle-voltage magnetizer (charging voltage : 1500[V], capacitor bank : 3000 [F]) coupled to iron-core fixture (8-pole rotor magnet of brushless DC motor). Fig.2(a) shows the 8-pole magnetizing fixture (8-pole rotor magnet of brushless DC motor). Also, capacitor discharge impulse magnetizer shown in Fig.2(b) is designed to magnetize the magnet of Fig.2(a).

4.2 Today's cost estimation results

The estimated cost using the basic cost assumptions described above and below, are given in Table 1. Results are shown for four different energy levels ranging from 1 to 10[KJ].

All five major cost components increase in increasing energy level. Labor costs for assembling them are not included. But, the estimated cost of today's real system is about three times of Table 1, assuming a small-size manufacturer's gain based on KOREA industrial structure. The results are referred to as "Today's costs", no credit is taken for future price reductions due to the benefits of mass production, technology improvements, or competitions.

5. Potential cost reduction estimation

We estimated the potential for cost reductions in capacitor discharge impulse magnetizer as a function of time. The assumptions and results are summarized in this section.

5.1 Learning curve analysis

Energy [KJ]	Capacitor Bank [$]	Step-up Transformer [$]	Semiconductor Devices [$]	Magnetizing Fixture [$]	Related Electronic Circuits [$]	Total Cost [$]
1	2,500	125	625	1,200	212.5	4,662.5
3	4,375	250	1,000	1,200	250	7,075
5	5,625	500	1,500	1,200	312.5	9,700
10	7,500	750	1,875	1,200	375	11,700

Table 1. Cost estimation of capacitor discharge impulse magnetizer

Table 2. Assumed production schedules and learning curve factor

End of Year	Magnetizer per Year	Total Magnetizers Built	Learning Curve Factor
1	1	1	1.000
2	4	5	0.596
3	8	13	0.438
4	14	27	0.346
5	22	49	0.286
6	44	93	0.232
7	44	137	0.205
8	44	181	0.188
9	44	225	0.175
10	44	269	0.165

We assumed that the magnetizer cost is reduced by 20[%] for each doubling in total systems produced (referred to as a 80[%] learning curve). A 80[%] learning curve is a assumed estimate based on KOREA industrial experience. Consequently, this leads to the following generalized relationship.[11]

$$C_p = C_1 \cdot p^{n'} \quad (7)$$

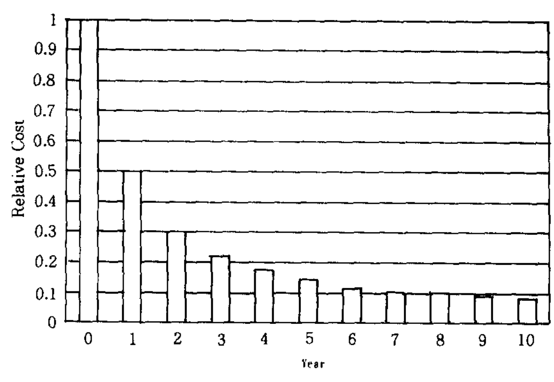
where C_p = cost of total magnetizer produced
p = total magnetizer produced
C_1 = cost of the first magnetizer
$n' = \ln 0.8 / \ln 2$

therefore, $C_p = Cl \cdot p^{-0.322}$ (7-1)

In order to determine the learning curve savings, we assumed a production schedule shown in Table 2. It assumes that production is ramped up rapidly in the first six years and then is constant is years 6~10. The learning curve analysis was applied to the capacitor bank, semiconductor devices and related electronic circuits as discussed below.

Since today's magnetizing fixture and transformer are fairly mature technology and its capability is not expected to improve greatly in the future, we did not apply a learning curve reduction to the costs. As a results of this assumption, we chose not to assume future cost reductions in the above two component's cost. We assumed that the cost of the capacitor bank, semiconductor devices and related electronic circuits were reduced by technology development with design improvements, mass production and competition. Increasing energy saving capability of the capacitor bank reduces the cost of capacitor bank. Therefore, we assumed that technologies of capacitor bank can be improved to give 5[%] by year 3, 10[%] by year 5 and 20[%] by year 10. Also, we assumed that the costs of semiconductor devices and related electronic circuits could be reduced by 50[%] for the first commercial system. We assumed that this can be achieved for the smaller systems with impulse magnetizer as the market and technology develop. For years 2~10, the learning curve factors from Table 2 are applied to the year one cost. Fig.3 shows the cost of a semiconductor devices and related electronic cir-

Fig. 3. Relative cost vs. time for a semiconductor devices and related electronic circuits of 3[KJ] magnetizer



End of Year	Cost [$]	Discount Factor	Present Value [$]
1	100	0.952	95.2
2	100	0.91	91.0
3	100	0.864	86.4
4	100	0.823	82.3
5	100	0.784	78.4
6	100	0.746	74.6
7	100	0.711	71.1
8	100	0.677	67.7
9	100	0.645	64.5
10	100	0.614	61.4
Net Present Value = $ 772.6			

Table 3. Cost reduction by depreciation

cuits of 3[KJ] magnetizer as a function of time relative to today's cost.

5.2 Estimation of cost by depreciation

A dollar available today is worth more than the same dollar available tomorrow, or next year, or ten years from now. If a cost of 100[$]/year for the next ten years is discounted at 5[%], it will have a present value of 772.6[$] as seen below:

The cost for the first year is 100[$]. This amount is multiplied by the discount factor of 0.952 to yield a present value of 95.2[$].

The discount factor is calculated by eq.(8):

$$\text{Discount Factor} = 1/(1+(D/100))^n \qquad (8)$$

where D = discount rate in [%]

n = number of years.

The discount factor is calaulated for the remaining years in the above example, and the discounted values are totaled to obtain a net present value of 772.6[$] for the sequence of cost during the ten years.

In case of considering the cost depreciation in this study, the total cost of magnetizer was more reduced by depreciation. We assumed that discount rate of cost is 5[%].

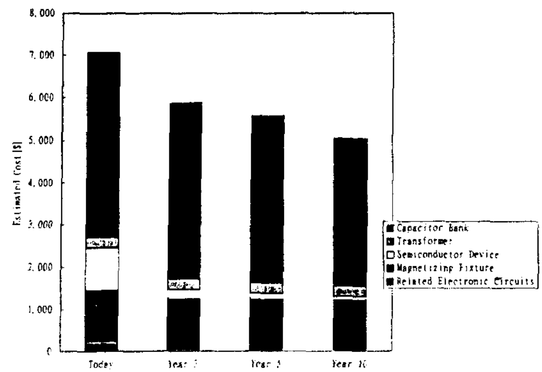
5.3 Summary of cost reduction

Table 4 summarized the results of the cost reduction analysis for the cases considered. As indicated, there are four energy levels ranging for 1 to 10[KJ]. Fig.4 shows the results for the 3[KJ] magnetizer graphically. For our assumptions, the overall cost is reduced by 83[%] by year 3, 79[%] by year 5 and 71.45[%] by year 10. There is a significant reduction in the semiconductor devices and related electronic circuits between 3 and 10 due to the technical improvements in the design.

Table 4. Final estimated cost for capacitor discharge impulse magnetizer

Energy [KJ]	Final Estimated Cost [$]			
	Today	year 3	year 5	year 10
1	4662.5	3883.4	3693.8	3394.1
3	7075	5880	5566.3	5053.1
5	9700	7440.7	7021.7	6349.5
10	11700	9567.8	9021.8	8135.6

Fig. 4. Cost estimation for 3[KJ] magnetizer with time



6. Conclusion

The method for the cost estimation of capacitor discharge impulse magnetizer using semiconductor switching device and the economical efficiency analysis has been presented. Today's magnetizers are dominated by the cost of capacitor bank, with a second major cost component being the magnetizing fixture. Technology improvements and cost reductions from mass productions and competition are expected to improve the costs over the next ten years. We project that a reduction to one-quarter of today's cost could be possible with aggressive market and technology development. Finally, we estimated the potential of cost by depreciation. Also, hand, operating costs should also drop with system automation using microprocessor.

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