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ABSTRACT

An experimental rig has been built to test a horizontal scroll compressor and a reciprocating compressor of similar size and capacity. The compressors were tested with refrigerant.R404A operating at varying evaporator and condenser temperatures. The paper provides much needed information regarding the efficiency of the compressors operating under the same conditions with the same system parameters. This paper also reports on investigations being carried out on the effect of refrigerant charge on both types of compressor. The results show that the scroll compressor generally produces cooling capacities and COPs that are equal to or greater than the reciprocating compressor. Both compressor types exhibit the same general characteristics with respect to system charge. In particular, COP is reduced with significant under- and over-charging. Superheat and subcooling are shown to be functions of system charge level for both compressors and thus may be used as a general indicator of charge level, irrespective of the compressor type.

INTRODUCTION

The scroll compressor has gained wide acceptance in recent years in commercial applications. The compactness and lightweight of scrolls along with apparent low sound and vibration level has made them very popular. One of the scroll compressor advantages is that the number of moving components is very low compared to reciprocating compressors. Also, it is reported that the volumetric and isentropic efficiencies are higher than similar sizes of reciprocating compressors. However, little information is available on how well it compares in performance with an equal size reciprocating compressor under similar load variation and refrigerant charge variation which can be useful when replacing reciprocating compressors with scroll compressors. The use of scroll compressor in supermarket packs which serve remote display cabinets have become widespead in the UK, (Hundy 1998). However, because of the height of the vertical scrolls they are yet to replace the small reciprocating compressors used in integral cabinets. Hence a horizontal scroll was used in order to establish its operation characteristics and evaluate whether it will be able to easily replace reciprocating compressors in integral display cabinets.

Background

Reciprocating Compressor

These are the most common type of compressor and are positive-displacement machines. They essentially comprise one or more single-action pistons, driven by a piston rod from a crankshaft, reciprocating within cylinders. Cylinders may form an inline 'V' or 'W' configuration, and can range in number from 1 to 16. Inlet and exhaust non-return valves allow gas in and out of the cylinders. The basic design is simple and highly developed, so reciprocating compressors are often lower in price than competing systems. A small reciprocating compressors will absorb less than 10kW, a medium sized-machine 10-50kW and a large machine 50kW and over. There is no practical limit to machine size and very large multi-cylinder machines are available although in practice rotary machines are more common over about 150kW motor power.

Scroll Compressor

The scroll compressor is a rotary positive-displacement machine used at present in small (5-35kW) air conditioning and heat pump units, and car air conditioning systems. A scroll is an involute spiral mounted on a flat plate. The scroll set comprises two scrolls: one is fixed and the other, phased 180°C from the first, moves around a fixed point on the fixed scroll (translates). As the moving scroll translates, gas enters the space between the scrolls at the edge of the scroll set. Further motion traps the gas in a crescent-shaped pocket formed between scrolls and propels the gas towards the centre of the scroll set. As the gas moves inwards, the volume of the pocket is reduced and the gas is compressed. Eventually the discharge port is uncovered and compressed gas is discharged. As several compression processes are in progress all the time, the gas flow is much smoother than in a piston type where the process is discontinuous.

Small scroll compressors offer several important manufacturing as well as performance advantages over reciprocating compressors. This is reflected in the worldwide trend to substitute reciprocating by rotary compressors in small capacity air-conditioning, heat pump systems and supermarket compressor packs. Mass production technologies developed through the widespread application of air-conditioners and the adoption of new wear resistance materials for the compression mechanism and new insulating materials for the motor windings, helped to overcome initial difficulties associated with clearance tolerances, sealing mechanism and component assembly. Detailed information regarding both types of compressor are found in O'Neill (1993).

Previous Work

There is not much study published that directly compares the scroll with the reciprocating compressor performance under different operational conditions. Payne and O'Neal (1995) conducted test on scroll and reciprocating compressor with comparable efficiency and capacity to assess the relative performance of the two compressors under frosting conditions and during defrost cycle of an 10.6 kW nominally sized air-to-air heat pump. The investigation focused on the transient performance of the two different system configurations. When the system was equipped with the scroll compressor it provided a slightly higher integrated COP of the two configurations. The reciprocating compressor produced heating capacity that was within 1% of the original scroll compressor. The reciprocating compressor produced a higher discharge superheat during frosting and defrost. Given that both systems produced discharge pressures that were within 3% during defrost, the reciprocating compressor produced higher-energy discharge gas, which reduced the defrost time over that of the scroll-compressor-equipped system.

Performance data however is available from the manufacturers of compressors which allows some comparison between the two types of compressor and provides suggestion to the users as to which model of scroll compressor can replace reciprocating compressors under similar load conditions.

There does exist some published literature dealing with the performance effect of varying refrigerant charge within vapour-compression system. Damasceno et. al (1991) investigated into the capability of predicting the effects of refrigerant charge on the steady state performance of air-air heat pump using a computer model validated against experimental work. The authors presented predicted values of heating and cooling capacity for various charge levels and concluded that careful measurement of the internal volumes was necessary and some minor modification in void fraction were required to enable good agreement between measured and predicted values. Farzad and O'Neal (1991), (1993) and (1994) reported work that studied the effect of various refrigerant charge on the performance of a 3ton (10kW) residential split system air conditioner with capillary tube expansion, thermal expansion valve (TXV) and a short tube orifice. Performance was found to degrade more generally with undercharge conditions than overcharge. The superheat at evaporator outlet was found to decrease with both increasing condensing temperature and charge level. Subcooling was observed to increase with increasing charge. However, due to its inherent quality the degradation of performance was much larger in capillary tube than the TXV and short tube orifice. The TXV and the short tube orifice were observed to be more sensitive to the outdoor temperature change than to the variation of charge.

The effect of refrigerant charge level on air-conditioning system was also examined by Goswami et.al.(1997). The authors concluded that charge level has a significant effect on the performance of air-conditioning systems at levels below 80% of normal. For a charge level of 90% of normal, the effect of COP and cooling capacity was found to be negligible. Bailey (1998) investigated the operation of an air-cooled chiller with a range of refrigerant charge levels. The author concluded that the chiller kW per ton was directly proportional to refrigerant charge level at charges of 70% of normal or greater. Below that charge, chiller kW per ton was inversely proportional to charge level. Subcooling temperature, discharge and suction pressure were all reported to be directly proportional to charge level whilst superheat was observed to be inversely proportional.

This investigation looks into the steady state performance and performance under varying refrigerant charge level for a vapour-compression system using hermetic scroll and reciprocating compressors.

EXPERIMENTAL INVESTIGATIONS

Test Facility

A simple water-water chiller facility was built in the laboratory to facilitate testing of scroll and reciprocating compressors. The system consisted of plate heat exchangers for evaporator and condenser, thermostatic expansion valve and hermetic scroll or hermetic reciprocating compressor depending on the compressor being tested. The hermetic scroll is a horizontal model with displacement of $2.08m^3$/hr while the reciprocating compressor has a displacement of $6.63m^3$/hr. The refrigeration system acted as the primary circuit and cooled a secondary glycol circuit to facilitate tests at evaporating temperature of below 0°C. The plate heat exchanger of the glycol circuit was loaded with mains water supply source while heat at the condenser was rejected at the condenser through a heat-exchanger supplied by water from mains water supply as a sink. The second heat-exchanger at the condenser side provided some pre-heating to the incoming supply water from the condenser outlet water. Figure 1 shows the schematic diagram of the system and Fig 2 shows a picture of the experimental rig.

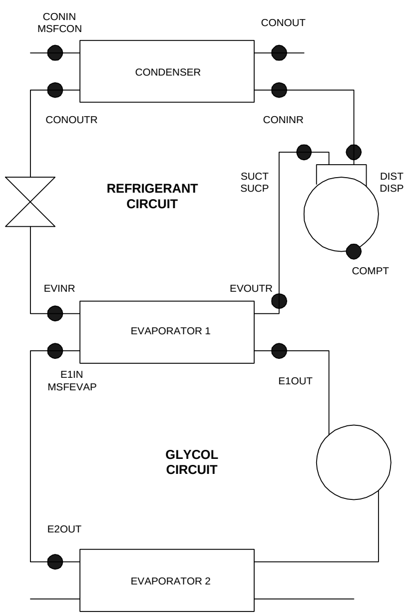

Figure 1: Schematic of the system

Figure 2: Picture of the experimental rig

Water and refrigerant temperatures were measured before and after each refrigerant circuit heat exchanger together with coolant flow rates, refrigerant pressures and compressor power consumption. Refrigerant R404a was used as a working fluid.

Procedure

Tests were carried out under steady state conditions for constant evaporating and condensing temperatures. For varying charge test the system was initially vacuumed and gradually charged in steps of 200grams. A digital scale was used to measure the weight of the charging refrigerant bottle. After each 200grams being charged the system was allowed to run for an hour to reach steady state.

RESULTS AND DISCUSSION

The performance of the system using the reciprocating and scroll compressors with refrigerant R404a was investigated. The system performance was compared at condenser temperatures of 30°C and 35°C under steady-state conditions.

Cooling capacity and coefficient of performance

The system cooling capacity for condenser temperatures of 30°C and 35°C is shown in Figures 3 and 4. The cooling capacity is shown to be generally higher for the scroll compressor although the increase is very low at the lower condenser temperature. The scroll compressor produces cooling capacities between 1% and 12% greater than the reciprocating compressor at condenser temperatures of 30°C and 35°C respectively.

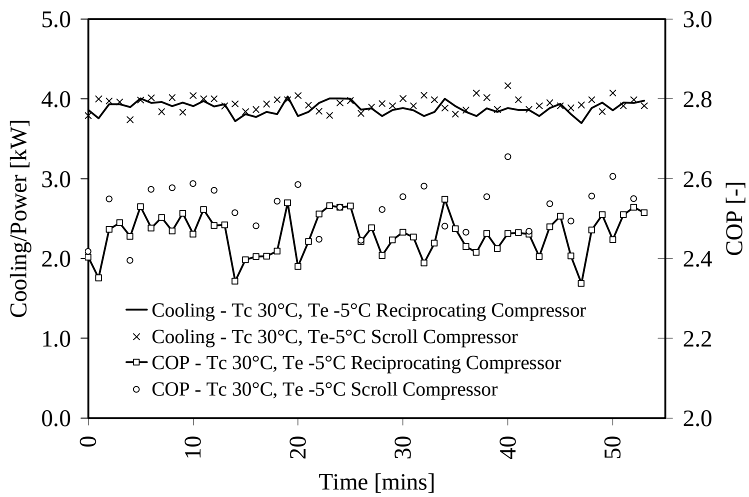

Figure 3: Comparison of compressor performance at a condenser temperature of 30°C

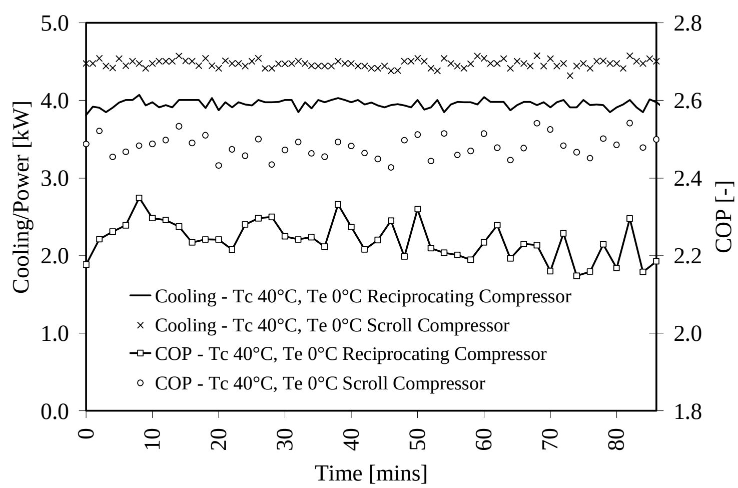

Figure 4: Comparison of compressor performance at a condenser temperature of 35°C

The scroll compressor consumes approximately the same amount of power as the reciprocating compressor, 1% lower at a condenser temperature of 30°C and 3% higher at 35°C on average. The coefficient of performance is also shown in Figures 3 and 4. For both condenser conditions, the scroll compressor delivers a higher COP than the reciprocating compressor. At a condenser temperature of 30°C, the scroll compressor has a COP 3% greater and a 35°C the COP is 10% higher on average.

Discharge temperature

Comparison of the operating parameters for the two compressors shows little significant difference with one exception. The compressor discharge temperature is considerably lower for the scroll compressor at both condenser temperatures. At 30°C, the scroll compressor produces a discharge temperature 11.3°C or 25% lower than the reciprocating compressor. At 35°C, the scroll compressor delivers a discharge temperature 10.5°C or 20% lower than the reciprocating unit. This reduction in discharge temperature can be attributed to the scroll compressor's liquid injection system used for cooling the motor.

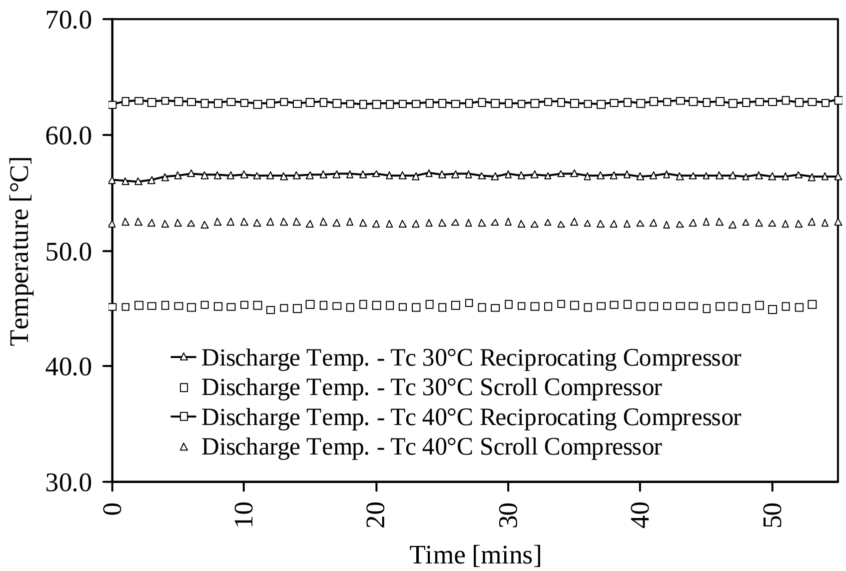

Figure 5: Comparison of compressor discharge temperatures

Charge tests

The system performance of the two compressors was also compared at different charge levels. The variation in performance with respect to charge level is important for fault detection systems which attempt to identify incorrect levels of system charge. Comparison of the two compressors enables those characteristics common to both to be discerned from those specific to each design. This allows the development of generic diagnostic rules which are applicable to systems with either type of compressor. The nominal charge level for the system is 1.3kg.

The cooling capacity and coefficient of performance of the two compressors against charge is shown in Figures 6 and 7. The scroll compressor tests are on-going and only tests at a condenser temperature of 30°C have been completed to date. Figure 6 shows that the scroll compressor produces slightly greater cooling capacity, approximately 0.1kW or 2% higher than the reciprocating compressor and that the variation with respect to charge level is small. This is consistent with the steady-state results at nominal charge level in the previous section.

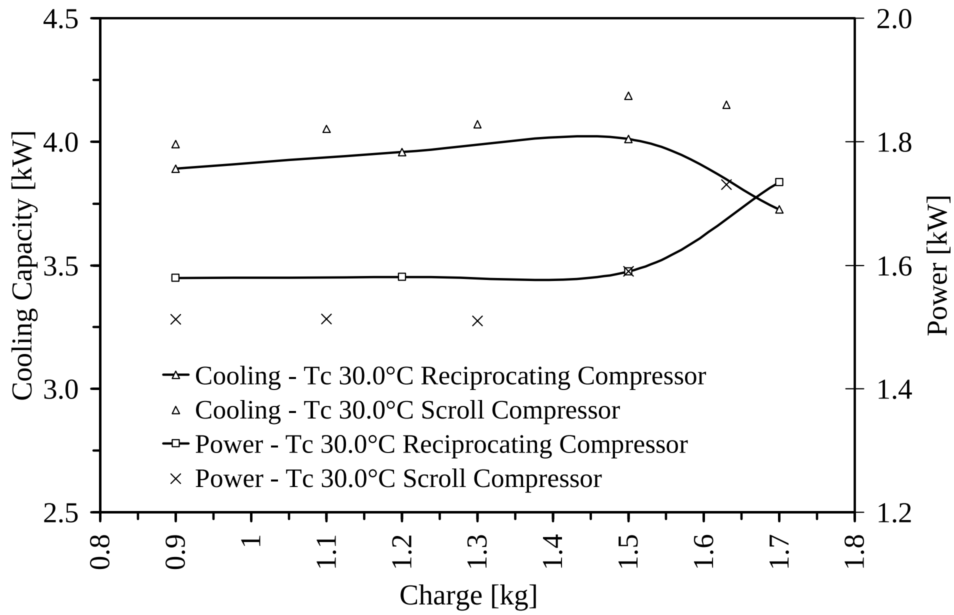

Figure 6: Cooling capacity and Power against system charge level

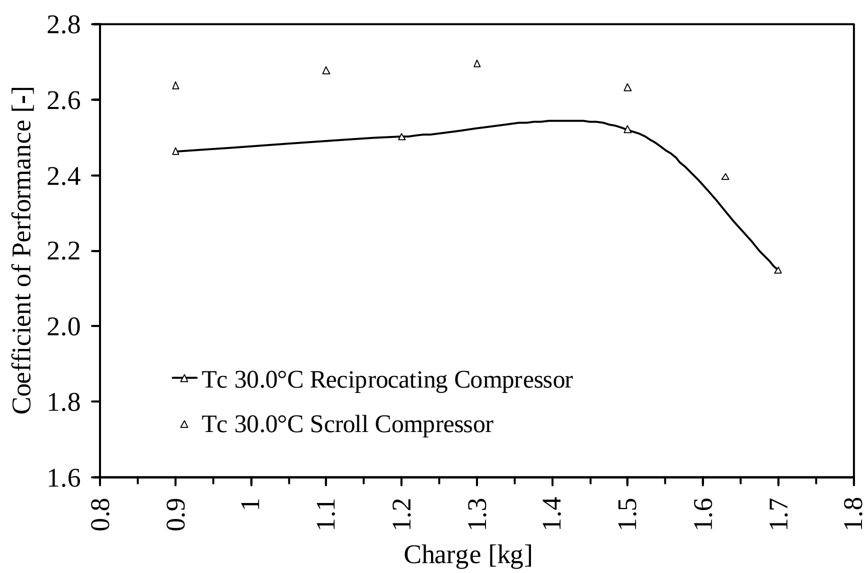

Figure 7: Coefficient of performance against system charge level

The coefficient of performance is also slightly greater for the scroll compressor at each charge level. Figure 7 shows that the scroll compressor produces COPs between 0.1 and 0.2 greater than the reciprocating compressor (between 4% and 8%), the greatest difference being found at lower charge levels. There is little variation in COP with respect to charge level at lower charge levels but a significant decrease for both compressor types at high levels of charge.

The variation in superheat and subcooling with charge level for the two compressors is shown in Figures 8 and 9. These two parameters may be used in fault detection systems as they provide an indication of the operation of the refrigeration system which is relatively independent of the evaporator and condenser operating conditions.

The scroll compressor is shown to produce similar characteristics for both superheat and subcooling with respect to the charge level. For both parameters, the scroll generates higher values than the reciprocating compressor. For superheating, the scroll compressor produces values between 1.0°C and 1.5°C higher and for subcooling, values are between 4.0°C and 12.0°C higher. The increased subcooling can be attributed to the lower discharge temperatures produced by the scroll compressor as a result of its liquid injection system.

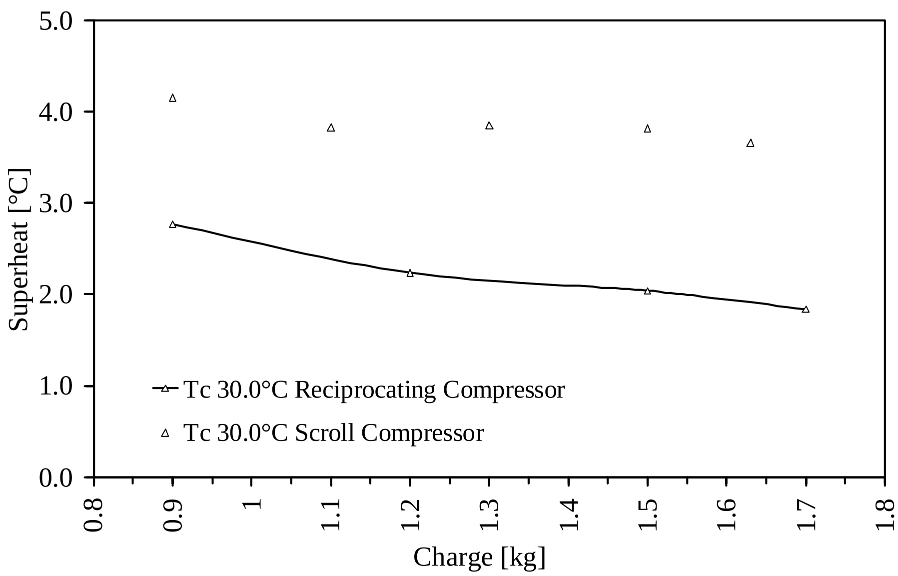

Figure 8: Superheating against system charge level

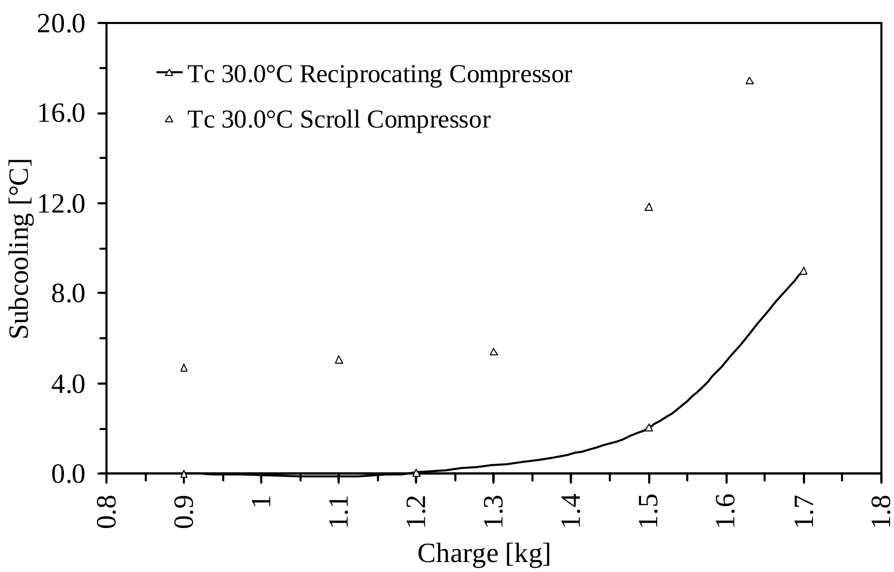

Figure 9: Subcooling against system charge level

CONCLUSIONS

A series of steady state performance experiments were carried out using a scroll and a reciprocating compressor at two condenser operating conditions. The results show that the scroll compressor generally produces cooling capacities and COPs that are equal to or greater than the reciprocating compressor. The performance of the scroll compressor improves relative to the reciprocating compressor at the higher condenser temperature. The use of a liquid injection system allows the scroll compressor to produce lower discharge temperatures than the reciprocating compressor.

A number of tests were also carried out to investigate the performance of both compressor types at varying charge levels. The scroll and reciprocating compressors show similar characteristics for cooling capacity and COP with respect to system charge level. The deterioration of the cooling capacity in the scroll is slower during overcharging than in the reciprocating but this is offset by the higher power consumption by the scroll at overcharged condition and so the COP variation is similar. Generally, COP is slightly reduced with under-charging and significantly reduced with over-charging.

The scroll and reciprocating compressors also show similar characteristics for superheat and subcooling with respect to charge level. For both compressor types, superheat decreases with increased charge level and subcooling increases significantly at charge levels above the nominal. The scroll compressor produces slightly greater superheat and considerably greater subcooling than the reciprocating compressor. The increase in subcooling for the scroll design is a result of the liquid injection system reducing the amount of de-superheating required in the condenser.

The results suggest that scroll compressors may deliver performance advantages over reciprocating compressors at some operating conditions, particularly at higher condenser temperatures and this is because of the lower discharge temperature observed in the scroll. Both compressor types exhibit the same general characteristics with respect to system charge. In particular, COP is reduced with significant under- and over-charging. Superheat and subcooling are shown to be functions of system charge level for both compressors and thus may be used as a general indicator of charge level, irrespective of the compressor type.

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