Case – 10 Single Stage Centrifugal Compressor

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Case Background:

This case is to exam the performance of a single stage centrifugal compressor and to show how to use the performance map to familiar the characteristics of the centrifugal compressor.

The operating conditions proposed for the compressor is shown below:

Capacity:	1,020 TR.
Refrigerant:	R-134a
Evaporative Temperature:	36°F
Condensing Temperature:	106°F
Suction piping loss:	1.2 Psi
Suction line superheat:	2°F
Discharge Piping Loss:	2.3 Psi
Input speed:	2,950 RPM.
Impeller Diameter of KA-65:	D =14.1”

Use the information shown in the section of Related Technical Data and Engineering Information for the Case, make a calculation to see if the TR is optimized to the compressor; if not, change the TR (all other data unchanged) that is more or less suitable for the compressor.

Derive the answer from the calculation for the following questions:

A. Are the operating conditions OK for the compressor? If not, what is the maximum TR suitable for the compressor?
B. What is the running Mach number?
C. Compressor Speed at the design point.
D. Adiabatic Efficiency.
E. Compressor Speed Code selected.
F. Power Consumption at design full load.
G. What is the approximate surge capacity (% of partial load), if the compressor is operating at constant head.

Related Technical Data and Engineering Information for the Case:

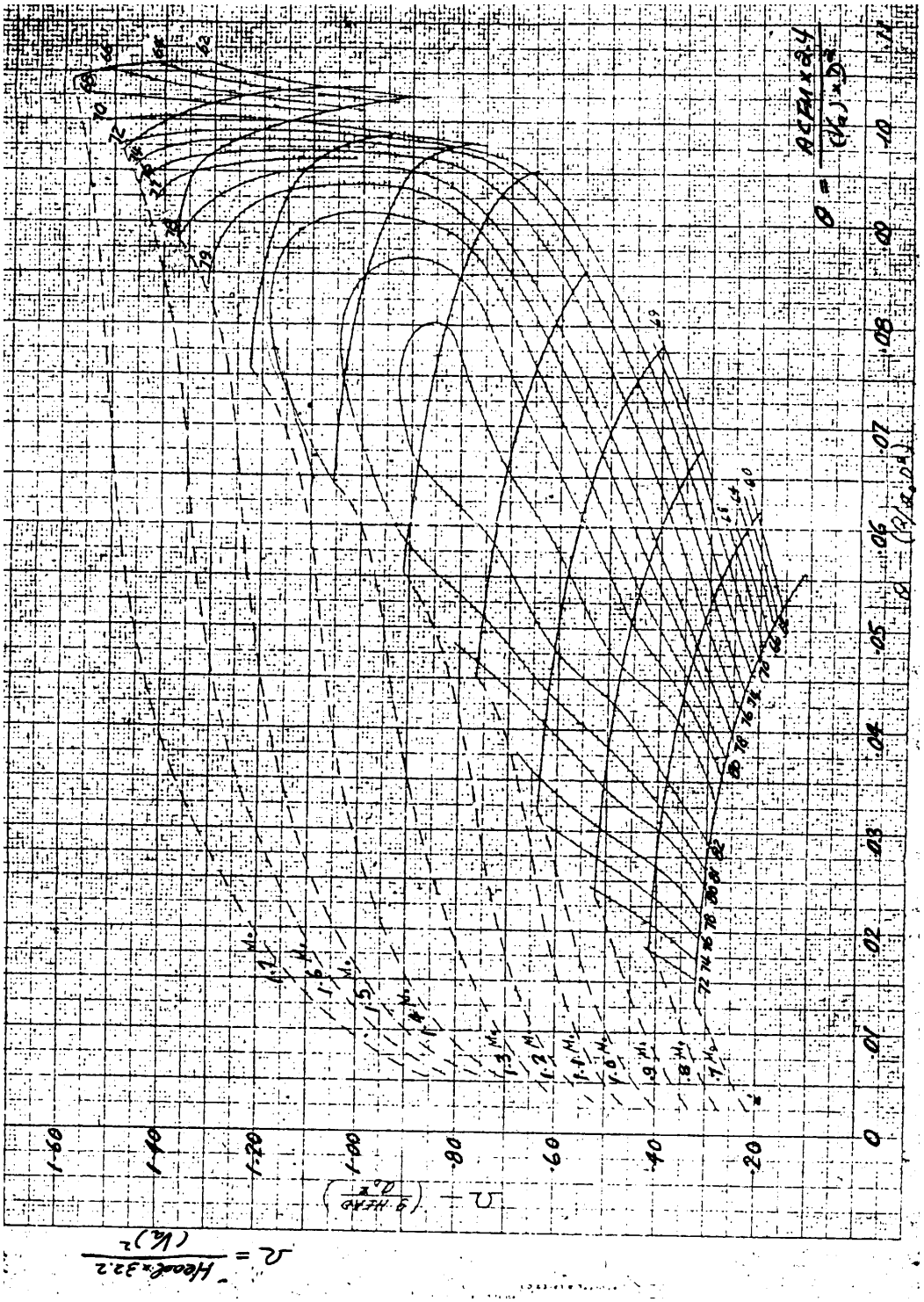

Figure 10-1 Typical Performance Map for KA-65 Centrifugal Compressor

2950 RPM INPUT
8" GEAR CENTERS

SPEED CODE	GEAR RATIO	RPM - IMPELLER SHAFT	KA-65		KA-73		HORSEPOWER LIMIT INTERNAL GEAR
			TIP SPEED (FT/SEC)	FRICTION HORSEPOWER	TIP SPEED (FT/SEC)	FRICTION HORSEPOWER	
UA	1.8421	5434.2	308.7	11	346.7	12.1	1379.1
UB	1.8800	5546.0	315.0	11.5	353.8	12.6	1373.9
UC	1.9189	5660.8	321.5	11.9	361.2	13.1	1370.7
UD	1.9589	5778.8	328.2	12.4	368.7	13.7	1363.3
UE	2.0000	5900.0	335.1	12.8	376.4	14.2	1360.1
UF	2.0423	6024.8	342.2	13.3	384.4	14.7	1353.8
UG	2.0857	6152.8	349.5	13.8	392.6	15.3	1349.6
UH	2.1304	6284.7	357.0	14.4	401.0	15.9	1341.1
UJ	2.1765	6420.7	364.7	14.9	409.6	16.5	1332.7
UK	2.2239	6560.5	372.6	15.4	418.6	17.2	1329.5
UL	2.2727	6704.5	380.8	16.0	427.8	17.8	1320.0
UM	2.3231	6853.2	389.3	16.6	437.2	18.5	1312.6
UN	2.3750	7006.3	398.0	17.2	447.0	19.1	1304.2
UP	2.4286	7164.4	406.9	17.8	457.1	19.8	1296.6
UQ	2.4839	7327.5	416.2	18.4	467.5	20.6	1288.3
UR	2.5410	7496.0	425.8	19.1	478.2	21.3	1279.9
US	2.6000	7670.0	435.7	19.8	489.3	22.1	1269.3
UT	2.6610	7850.0	445.9	20.5	500.8	22.8	1259.8
UU	2.7241	8036.1	456.5	21.2	512.7	23.7	1247.1
UV	2.7895	8229.0	467.4	22.0	525.0	24.6	1235.5
UW	2.8571	8428.5	478.7	22.8	537.7	25.5	1225.0
UX	2.9273	8635.5	490.5	23.6	550.9	26.4	1212.3
UY	3.0000	8850.0	502.7	24.4	564.6	27.3	1198.6
UZ	3.0755	9072.7	515.3	25.2	578.8	28.3	1184.8
VA	3.1538	9303.7	528.5	26.2	593.6	29.3	1170.0
VB	3.2353	9544.1	542.1	27.2	608.9	30.4	1152.1
VC	3.3200	9794.0	556.3	28.1	624.9	31.5	1140.5
VD	3.4082	10054.2	571.1	29.1	641.5	32.7	1122.5
VE	3.5000	10325.0	586.5	30.2	658.7	33.8	1106.7
VF	3.5957	10607.3	602.5	31.3	676.7	35.2	1090.8
VG	3.6957	10902.3	619.3	32.5	695.6	36.5	1075.0
VH	3.8000	11210.0	636.7	33.7	715.2	37.8	1058.1
VJ	3.9091	11531.9	655.0	34.9	735.7	39.3	1040.2
VK	4.0233	11868.7	674.1	36.2	757.2	40.8	1024.3
VL	4.1429	12221.6	694.2	37.6	779.7	42.4	1006.4
VM	4.2683	12591.5	715.2	39.1	803.3	44.1	988.4
VN	4.4000	12980.0	737.3	40.6	828.1	45.8	968.4
VP	4.5385	13388.6	760.5	42.2	——	——	948.3
VQ	4.6842	13818.4	784.9	43.8	——	——	929.3
VR	4.8378	14271.5	810.6	45.4	——	——	913.4

LOW SPEED SHAFT AND COUPLING LIMIT

1046.6 HORSEPOWER

Figure 10-2 Gear Codes for KA-65 Centrifugal Compressor For 2,950 RPM Motor Drive

Cogitation

Compressor calculation:

Recap the operating conditions:

Capacity:	1,020 TR.
Refrigerant:	R-134a
Evaporative Temperature:	36°F
Condensing Temperature:	106°F
Suction piping loss:	1.2 Psi
Suction line superheat:	2°F
Discharge Piping Loss:	2.3 Psi
Input speed:	2,950 RPM.

Compressor discharge and suction conditions:

Discharge Pressure = 152.03 + 2.3
= 154.33 Psia

Suction Pressure = 46.02 – 1.2
= 44.82 Psia

Suction Temperature = 36 + 3
= 38°F

Compressor
Suction Conditions: 44.82 Psia, 38°F

Refrigeration Load = 1,020 TR

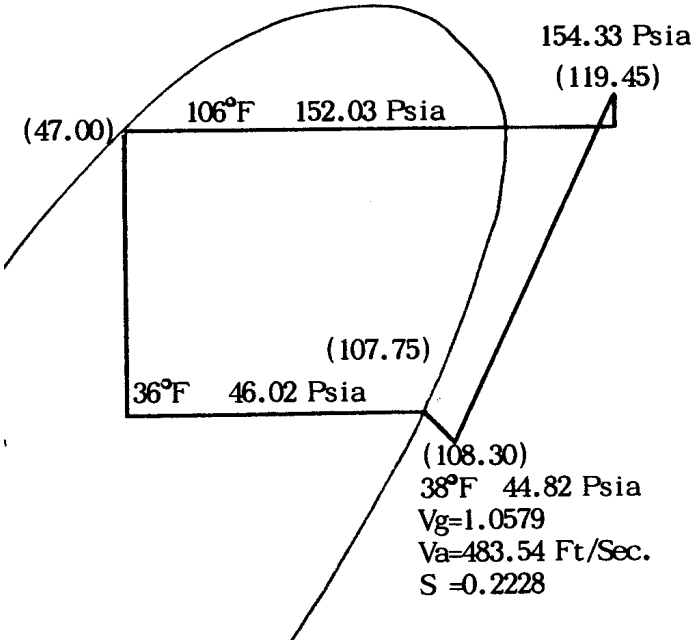

Figure 10-3 P-H Diagram for the Case

The operating point for the compressor is determined by the factors of Θ and Ω.

$$\text{Flow, Lbs/Min} = \frac{200}{\text{Refrigeration Effect}} \times \text{TR}$$

$$= \frac{200}{107.75 - 47.00} \times 1020$$

$$= 3{,}358.03 \text{ Lbs/Min.}$$

$$\text{ACFM} = (\text{Lbs/Min}) \times V_g$$

$$= 3{,}358.03 \times 1.0579 = 3{,}552.46 \text{ ACFM}$$

$$D^2 = (14.1)^2 = 198.81$$

$$V_a = 483.54 \text{ Ft/Sec.}$$

Head = (119.45 – 108.30) x 778
= 8,674.70 Ft.

$$\Theta = \frac{ACFM \times 2.4}{V_a \times D^2}$$

$$= \frac{3552.46 \times 2.4}{483.54 \times 198.81}$$

= 0.0887

$$\Omega = \frac{Head \times 32.2}{V_a^2}$$

$$= \frac{8674.70 \times 32.2}{(483.54)^2}$$

= 1.195

From the Compressor Map Figure 10-1, at $\Theta = 0.0887$ $\Omega = 1.195$

Obtain the Mach number and the compressor efficiency:
$M_o = 1.408$
$E_{ff} = 79.6\%$

From the formula:

$$M_o = \frac{T_s}{V_a}$$

Compressor design speed required to generate the Mach number:
$T_s = M_o \times V_a$

= 1.408 x 483.54 = 680.8 Ft./Sec.

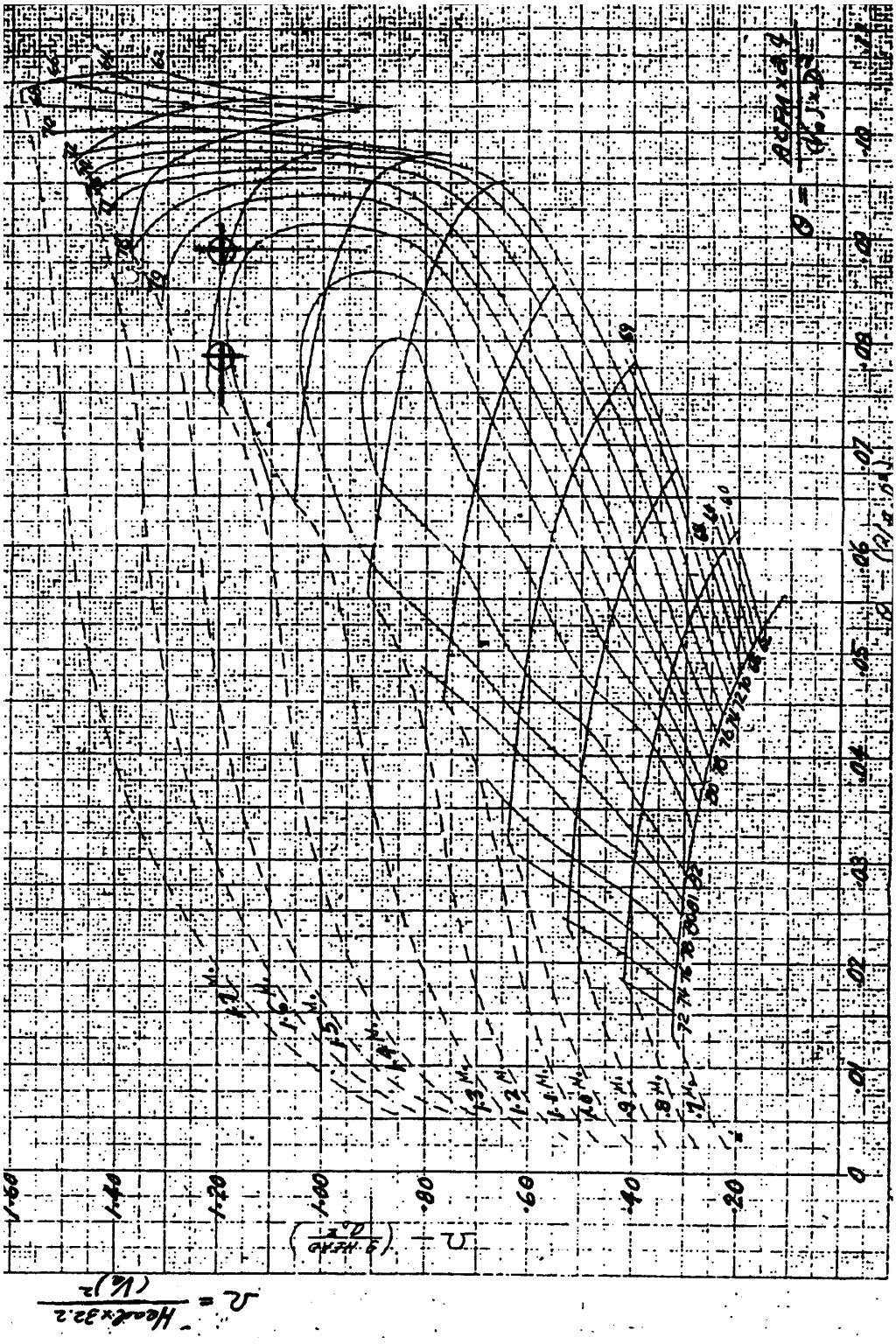

Figure 10-1A Operating Points for KA-65 Compressor

2950 RPM INPUT
8" GEAR CENTERS

SPEED CODE	GEAR RATIO	RPM - IMPELLER SHAFT	KA-65		KA-73		HORSEPOWER LIMIT INTERMEDIATE GEAR
			TIP SPEED (FT/SEC)	FRICTION HORSEPOWER	TIP SPEED (FT/SEC)	FRICTION HORSEPOWER	
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VJ	3.9091	11531.9	655.0	34.9	735.7	39.3	1040.2
② → VK	4.0233	11868.7	674.1	36.2	757.2	40.8	1024.3
① → VL	4.1429	12221.6	694.2	37.6	779.7	42.4	1006.4
VM	4.2683	12591.5	715.2	39.1	803.3	44.1	988.4
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Figure 10-2A Gear Code Selections for the Compressor

Note: Compressor efficiency and part load performance can be improved by changing the impeller profile design. Ask the compressor manufacturer for a better energy consumption selection for energy conservation application.

From the chart of Figure 10-2, for KA-65 compressor at T_s = 694.2 Ft/Sec.
Select Gear Code VL, Compressor Speed = 12,221.6 RPM

FHP = 37.6 HP

Compressor Power Consumption:

$$GHP = \frac{\text{Flow x Head}}{33000 \times E_{ff}} = \frac{3358.03 \times 8674.70}{33000 \times 0.796}$$

$$= 1{,}109.0 \text{ HP}$$

SHP = GHP + FHP

= 1,109.0 + 37.6 = 1,145.2 HP

Check Limitations:
From Figure 10-2 at T_s = 694.2 Ft/Sec.
Maximum HP limit for Internal Gear for Gear Code VL is 1,006.4 HP
Maximum HP limit for low speed shaft and the coupling is 1,046.6 HP

The SHP exceeds both Internal Gear limitation; the Low Speed Shaft and Coupling limits, therefore the selection is no good.

Try to reduce the TR while to maintain all other operating conditions not changed.

<u>Try to reduce the cooling load to 900 TR</u>:

$$\text{Flow, Lbs/Min} = \frac{200}{\text{Refrigeration Effect}} \times \text{TR}$$

$$= \frac{200}{107.75 - 47.00} \times 900$$

$$= 2{,}962.97 \text{ Lbs/Min.}$$

ACFM = (Lbs/Min) x V_g

= 2,962.97 x 1.0579 = 3,134.52 ACFM

$D^2 = (14.1)^2 = 198.81$

$V_a = 483.54$ Ft/Sec.

Head = (119.45 – 108.30) x 778
= 8,674.70 Ft.

$$\Theta = \frac{ACFM \times 2.4}{V_a \times D^2}$$

$$= \frac{3134.52 \times 2.4}{483.54 \times 198.81}$$

$$= 0.0783$$

$$\Omega = \frac{Head \times 32.2}{V_a^2}$$

$$= \frac{8674.70 \times 32.2}{(483.54)^2}$$

$$= 1.195$$

From the Compressor Map Figure 10-1A, at $\Theta = 0.0783$ $\Omega = 1.195$

$M_o = 1.385$
$E_{ff} = 79.86\%$

$$M_o = \frac{T_s}{V_a}$$

$T_s = M_o \times V_a$

$= 1.385 \times 483.54 = 669.7$ Ft./Sec.

From Figure 10-2A:

Select Gear Code VK, T_s = 674.1 Ft/Sec. Compressor Speed 11,868.7 RPM

FHP = 36.2 HP

Power Consumption Calculation:

$$GHP = \frac{\text{Flow x Head}}{33000 \times E_{ff}} = \frac{2962.97 \times 8674.70}{33000 \times 0.7986}$$

$$= 975.3 \text{ HP}$$

SHP = GHP + FHP
= 975.3 + 36.2 = 1,011.5 HP

Check Limitations:

Maximum HP limit for Internal Gear for Gear Code VK is 1,024.3 HP
Maximum HP limit for low speed shaft and the coupling is 1,046.6 HP

Selection OK, use 900 TR instead of 1,020 TR

Surge Point at constant head $\theta = 0.0735$

$$\text{Percent Partial Load} = \frac{0.0735}{0.0783} = 94\%$$

Conclusion:

A. 900 TR is recommended.
B. Operating Mach number: Mo = 1.385.
C. Adiabatic efficiency: E_{ff} = 79.86%
D. Speed Code selected: VK
E. Compressor Speed: 11,868,7 RPM
F. Power Consumption at full load: 1,011.5 HP.
G. Surge point at constant head: 94%