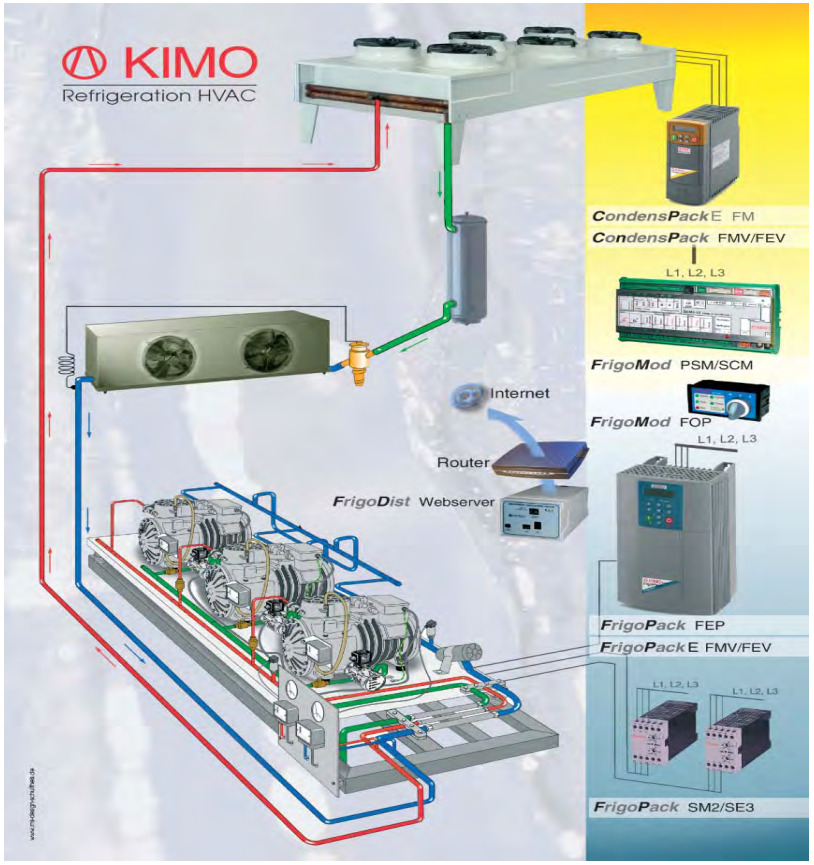

Frequency Inverters and Interaction with Refrigerant Compressors

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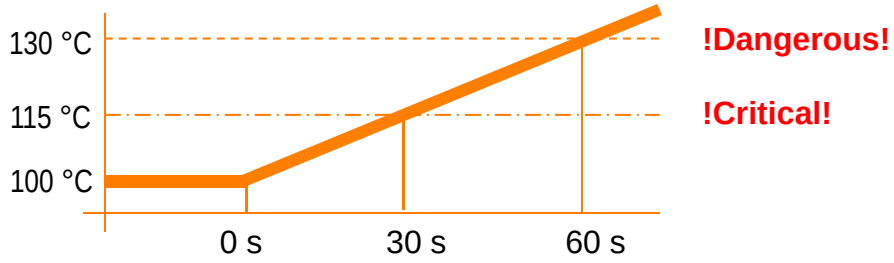
ART OF COMPRESSION
COLLOQUIUM
3rd May, 2012

CONTENTS

Frequency Inverters and Interaction with Refrigerant Compressors
Priorities

Avoiding motor winding overtemp. by stalled start



Protecting the compressor

- Danger of too small starting torque
- Stall detection ➔ Immediate current interruption
- Importance of inhibit time for motor to cool down before until next start attempt

Optimum use of an inverter

- Achieving the highest possible starting torque (Why is vector control not usually suitable?)
  $t_{winding}$: -20 ... 100 °C ➔ R_{Cu}: 100 ... 147 %

Economic considerations

- Integrated compressor protection
- Using the smallest possible frequency inverter
- Obtain more refrigeration capacity from compressor (70 Hz ➔ approx. 40 % more capacity)

Section of inverter size: **Design Method "2004"** (classical)

METHODOLOGY

- Look up: **Maximum Motor current** (compressor software)
- Consider: **Compensation Factor Fc** for compressor start
- Estimate: **Motor Starting Current** required
- Select: **Frequency Inverter** ($I_{max\ inverter}$ > Motor Starting Current)

- **2-cylinder : F_2 = 2.0**
- **4-cylinder: F_4 = 1.6**
- **6-cylinder: F_6 = 1.5**

ADVANTAGES

- Ensures compressor safety
- Simple to use
- Universal

LIMITATIONS

Does not consider:

- Refrigerant properties
- Small-motor low-temperature compressors
- Pull-down in a multi-compressor rack
- Often leads to oversizing of inverter

Section of inverter size: **Design Method "2012"** (proposal)

METHODOLOGY

- Choose: **Starting SCENARIO** (t_0, t_c)
- Look up: **Motor current** at **Reference Point** (R404A: +5/+45 °C)
- Consider: **Refrigerant Factors** (Base Refrigerant: R404A)
- Consider: **Compressor Types**, **Starting Torque Factors** (1.0 … 2.0)
- Consider: **Rack Assisted Starting (RAS)** (pull-down before start ➔ t_0)
- Consider: **Ambient temperatures** (t_{amb} ➔ t_c)
- Calculate: **Motor Starting Current** required (from motor equivalent circuit)
- Select: **Frequency Inverter** ($I_{max\ inverter}$ > Motor Starting Current)

ADVANTAGES

More economic design whilst ensuring compressor safety
(often selection of smaller inverter possible)

LIMITATIONS

Requires selection software

(too complicated for manual selection)

Design Method “2012”
Compressor Starting **SCENARIOS**

SCENARIO I

Starting following pressure equalization

- Realistic:
  t_0, t_c ≈ t_{amb}
- Starting:
  - Low torque (small inverter)
  - Not usually relevant for refrigeration

SCENARIO II

Starting following power failure at high t_{amb}

- Proposed reference point:
  R404A: t_0: +5 / t_c: +45 °C
- Realistic worst-case starting points:
  - t_0: 0…10 °C
  - t_c: t_{amb} max. (e.g. 43 °C)
- Consider refrigerant
- Starting:
  - High torque (large inverter)
  - More on next slides

SCENARIO II + RAS

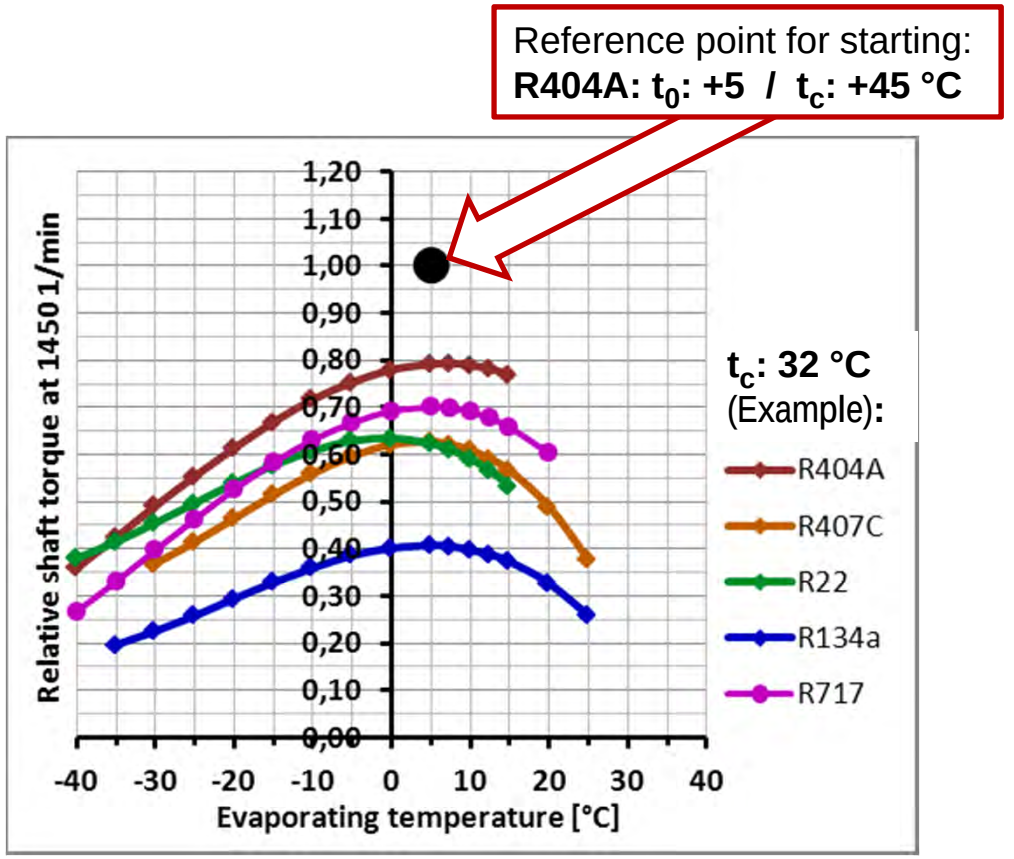
Starting following power failure at high t_{amb} + Rack-Assisted Starting (RAS)

- Practical possibilities:
  - MT: **R404A: t_0 <= 0 °C**
  - MT: **R134a: t_0 <= 0 °C**
  - LT: **R404A: t_0 <= -20 °C**
- Possible configurations:
  - Single compressor with bypass
  - 2x compress. each with bypass
  - >= 3x compressors
- Starting:
  - Medium torque (medium inverter)
  - More on next slides

Design Method “2012”

Reference point for starting, Refrigerant Factors

EXAMPLE: Mid-range, **open semi-hermetic** compressor



METHODOLOGY

- Shaft power / Drehzahl (rad/s) (from compressor software) ➔ corresponds to torque
- Choose highest torque which can occur

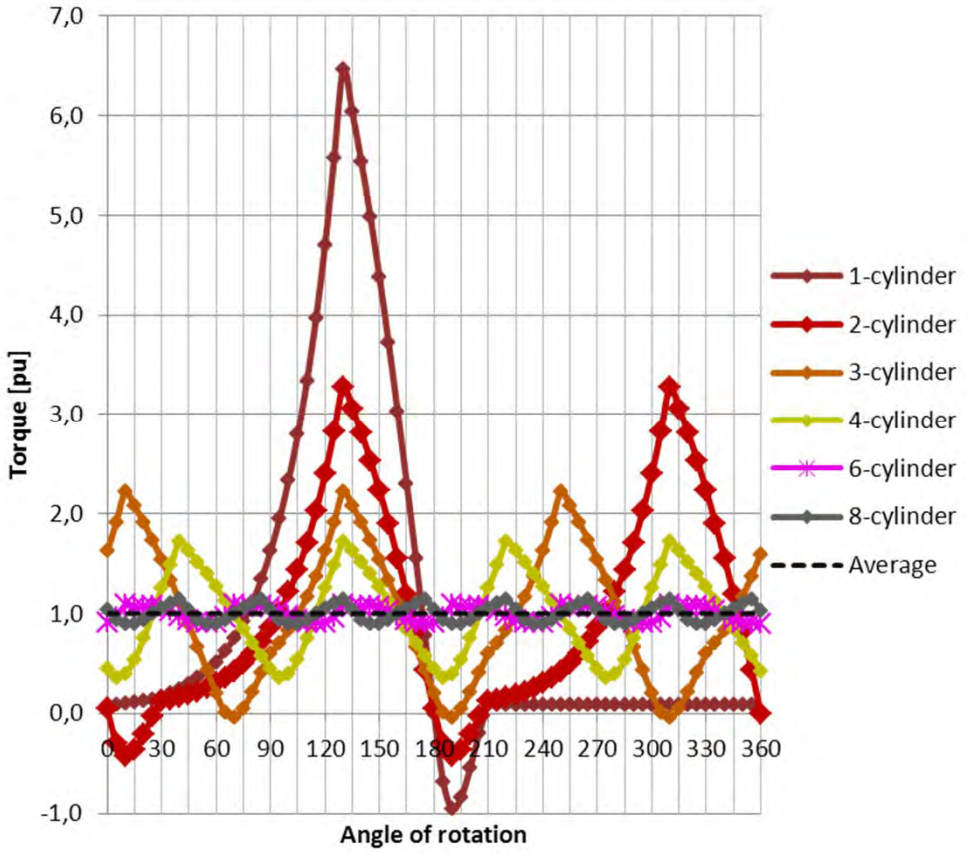
Chosen Refrigerant factors for $t_c = t_{amb}$ =43 °C

- R404A / R507A: 0.97
- R407C: 0.80
- R22: 0.85
- R134a: 0.55
- R717 / R727: 0.83

Design Method “2012”

Compressor types, Torque Starting Factors

EXAMPLE: Torque / Angle curves for a **rotating** reciprocating compressors



REQUIREMENT

- Frequency Inverter + Motor must bring at least the peak torque to guarantee starting

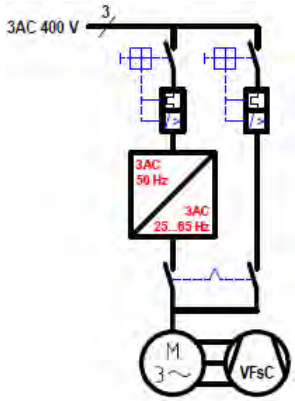
Chosen **Torque Starting Factors** (not same as current)

- 2-cylinder: 2.00x
- 3-cylinder: 1.60x
- 4-cylinder: 1.35x
- 6-cylinder: 1,30x
- 8-cylinder: 1.20x
- Scroll, screw: 1.20x

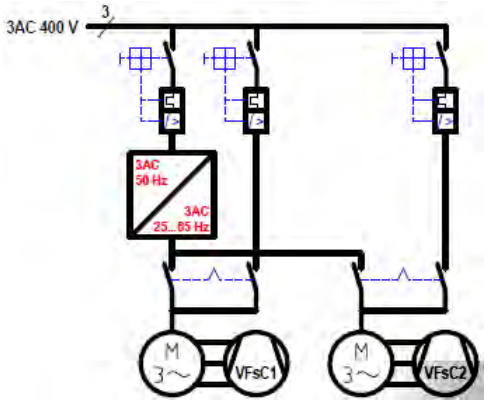
Design Method “2012”

Rack Assisted Starting (RAS), Ambient Temperatures

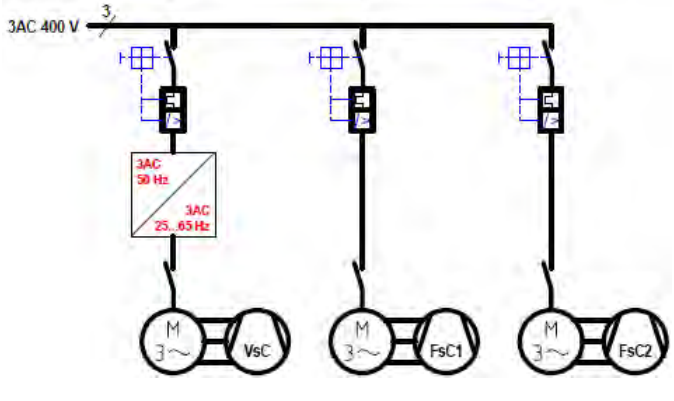
Possible RAS power circuits:



1x VsC compressor

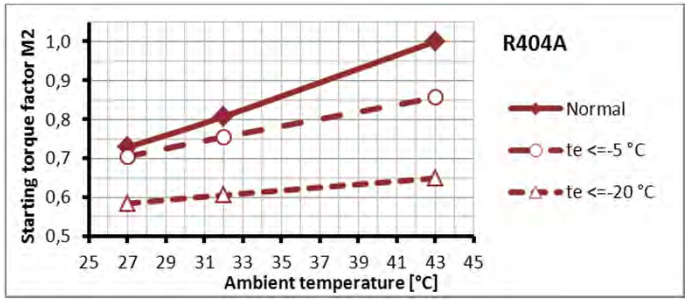


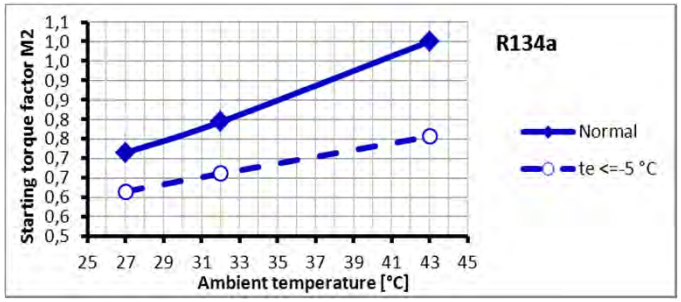
2x VFsC compressors



1x VsC + ≥2x FsC compressors

Torque reductions



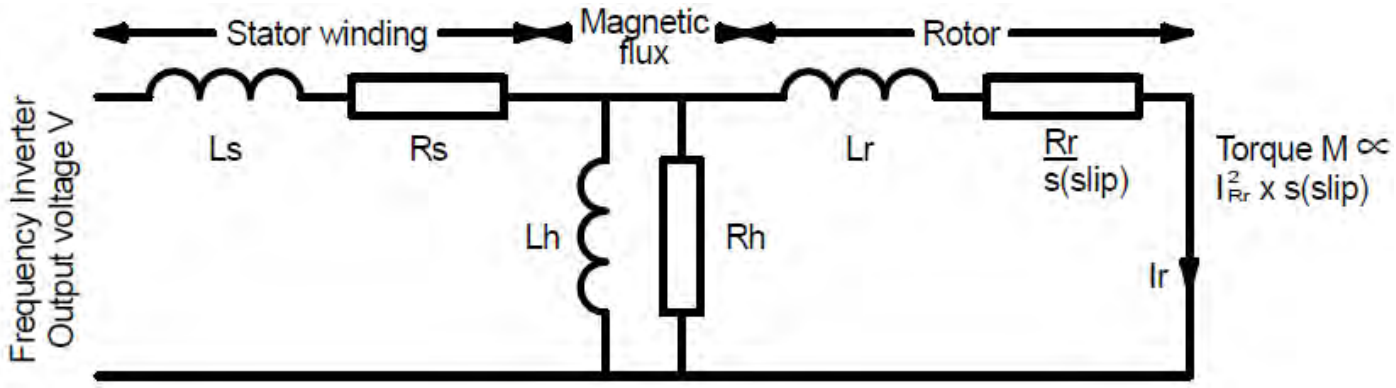


Control:

- **Intelligent rack controller required**

Design Method “2012”
Motor Starting Current ?

Methodology: Use motor electrical equivalent circuit



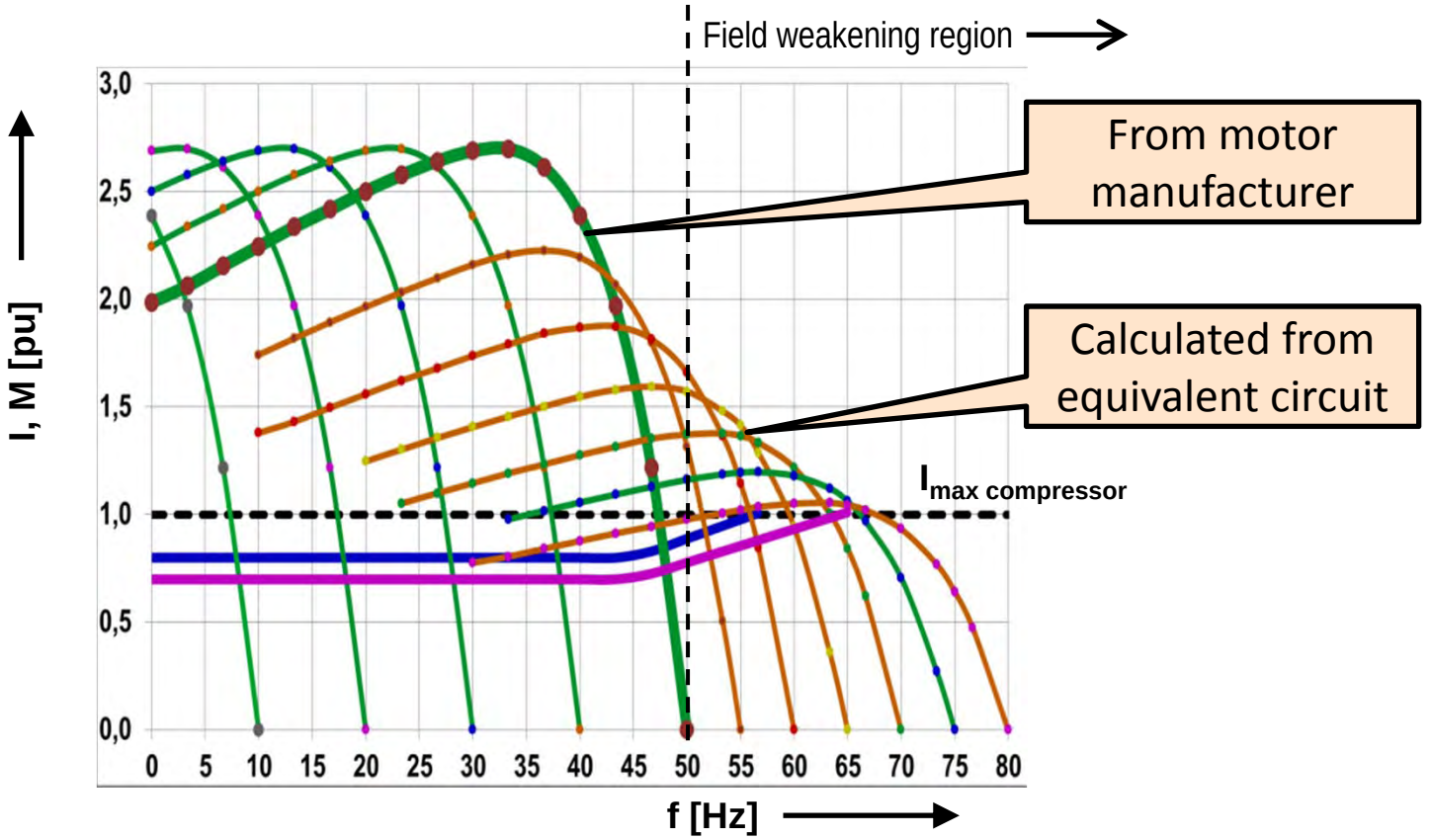
Problem: How can we identify the motor parameters ?

Solution: Use available standard data from compressor software:

- DOL current: I_{DOL}
- Max. motor current: I_{max}
- Min. motor current: I_{min}
  (e.g. with R134a at -30 / 20 °C with CC if >= 4 cylinders)
- Rated speed: n_{rat}
- Nummerical data fitting

Design Method “2012”

Starting current, Max. Frequency?



Results:

- Optimum inverter parameter settings
- Inverter current for reliable starting
- Maximum compressor frequency

Design Method “2012”

Which types of inverter are most suitable?

Industrial inverters

Starting torque:	100 %
Stall protection:	Special software required
Start timings:	Special software required
Current limit:	Special software required
Compressor diagnostics:	Special software required
Controls:	External required

Refrigeration Inverters

Starting torque:	120 ... 125 % (benchmarked with R744-TC starting)
Stall protection:	Standard
Start timings:	Standard
Current limit:	Standard
Compressor diagnostics:	Standard

Integrated intelligent control:	- p_0 , p_c
	- Monitoring:
	  - Suction superheat
	  - Discharge temperature
	- Rack control

Design Method “2012”

How can selection software assist?

Input Data:

Manufacturer [BITZER ... SCI]

Refrigerant [R134a ... R744_TC]

Type of compressor (+ no. of cylinders) [semi-hermetic, 2-cylinder ... Rotary, semi-hermetic]

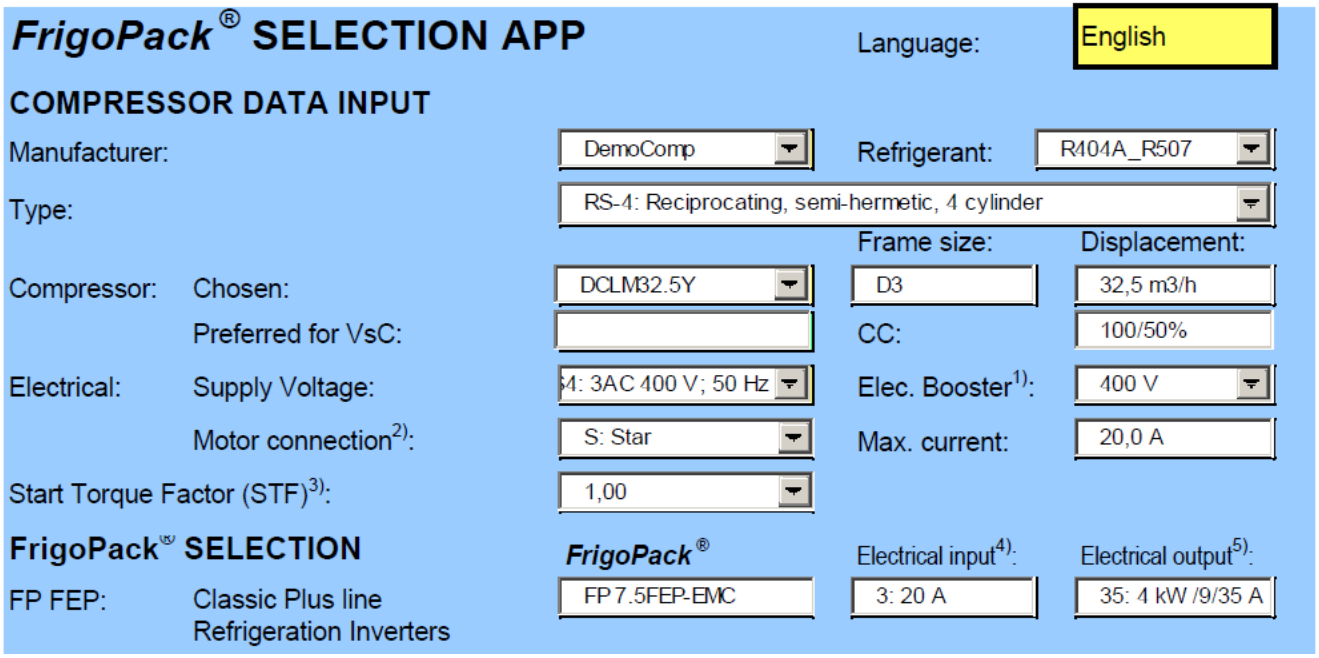
Choice of compressor [....]

Supply Voltage [3AC 230 V ... 3AC 480 V]

Elec. Booster [400 / 440 / 480 V]

Motor connection [Star, Delta, Part Winding]

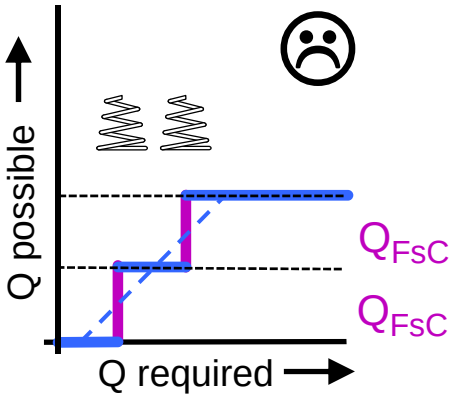
Start Torque Factor [1.0, 1.9, 1.8]



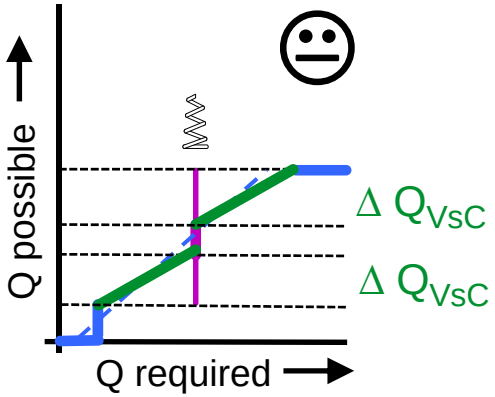
IV Compressor Rack Design:
What is the Control Factor?

Definition: Control Factor CF = $\frac{\text{Capacity Variation of Variable-speed Compressor } (\Delta Q_{VSC})}{\text{Step capacity of Fixed-speed Compressor } (Q_{FSC})}$

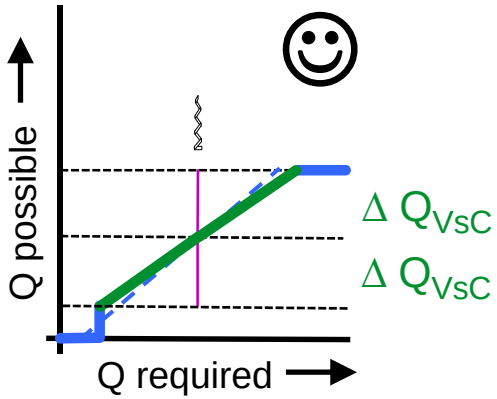
Examples: 1x Variable-speed Compressor (VsC) + 1x Fixed-speed Compressor (FsC)



CF = 0%
Step control



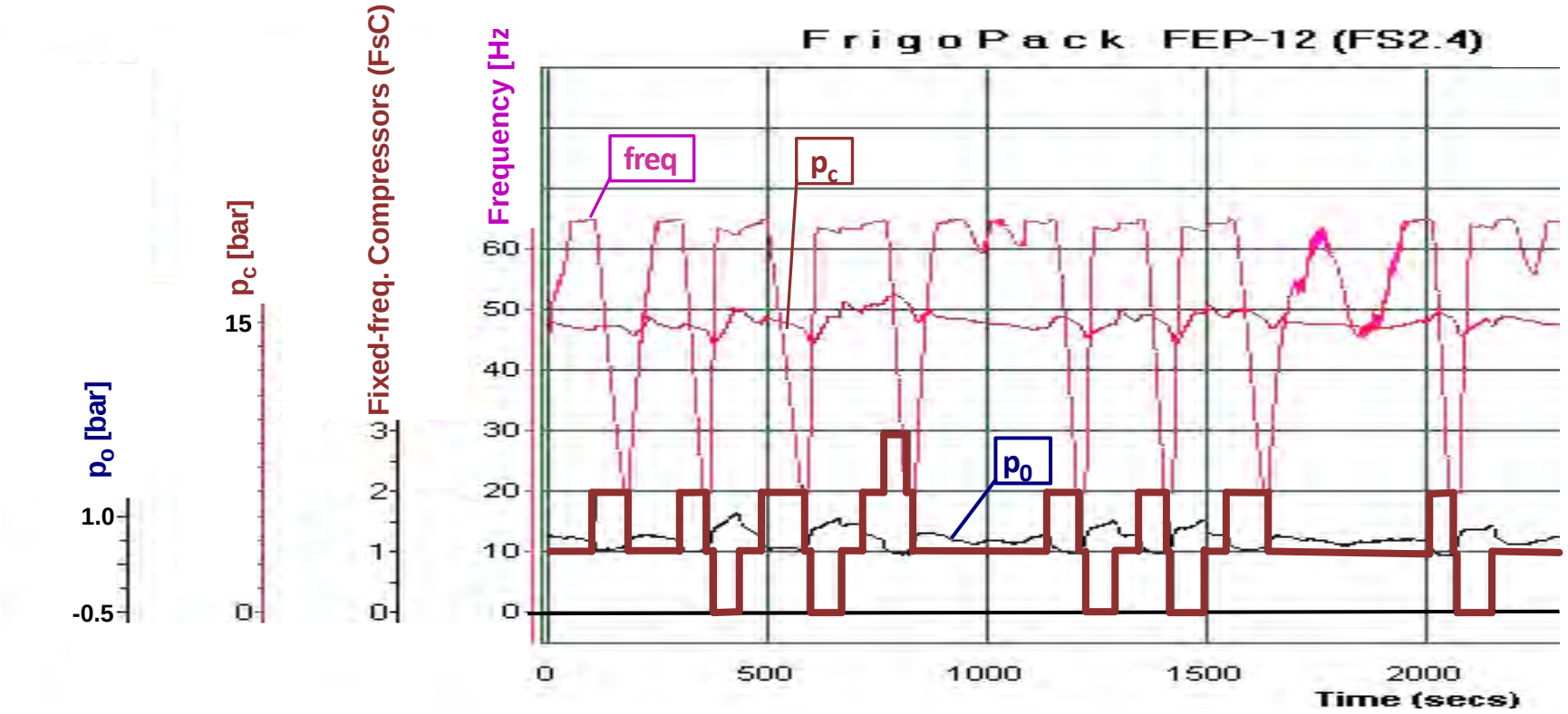
CF = 60%
Just acceptable



CF = ≥100%
Excellent

Design target: CF ≥80%

IV Compressor Rack Design:
Example of poor Control Factor

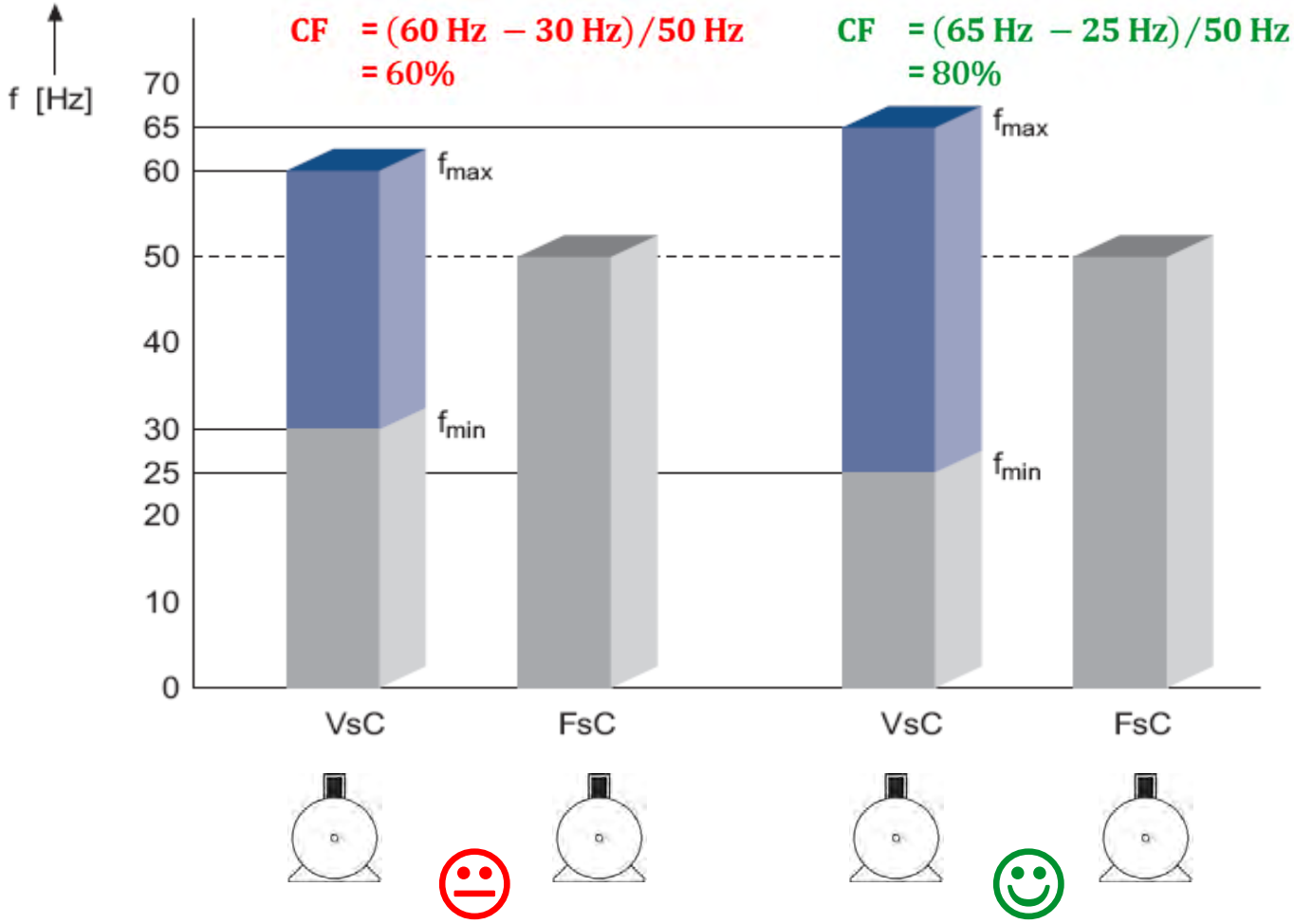


Installation:
Supermarket with
4 compressor rack

Control Factor:

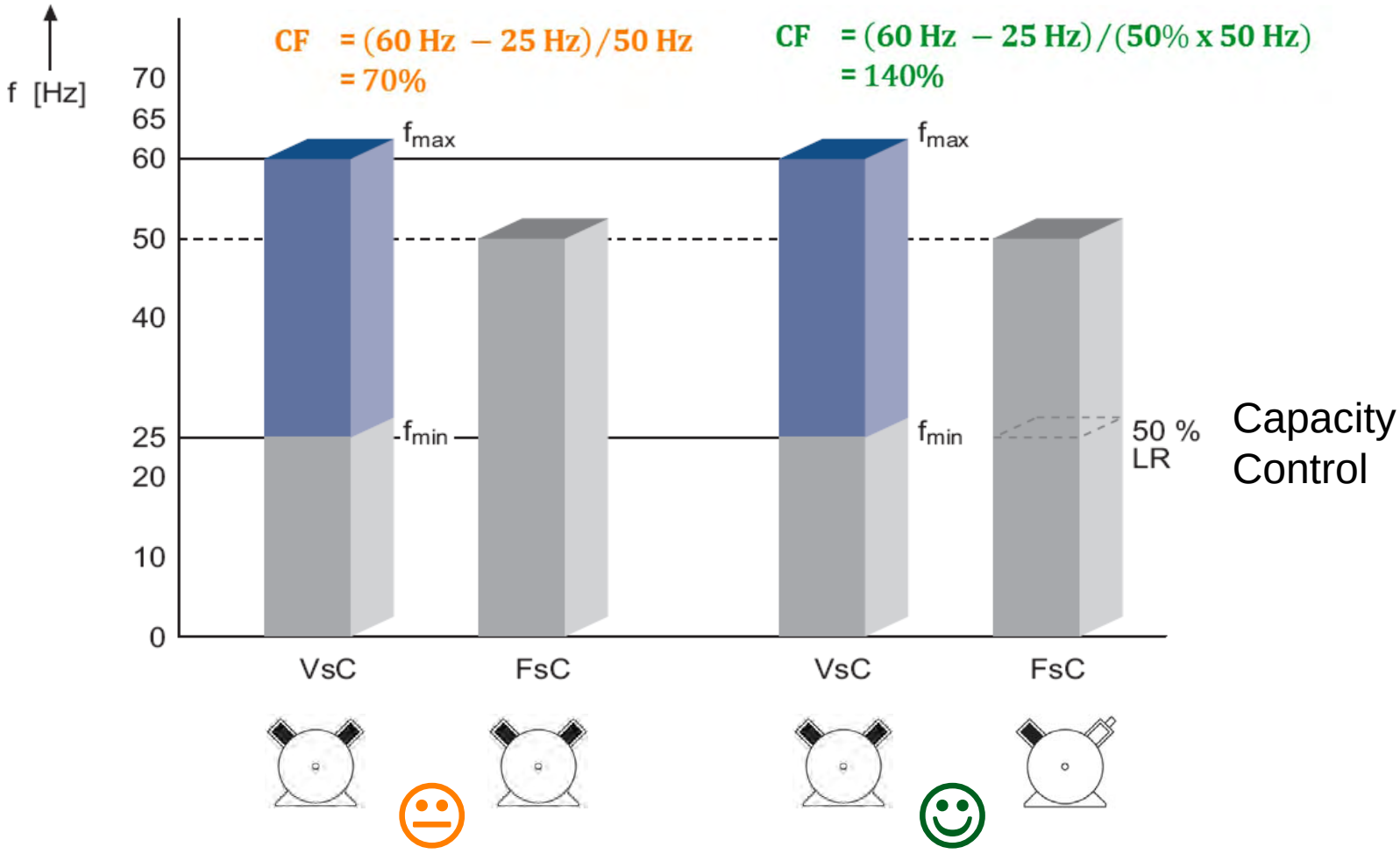
Originally:	25 ... 60 Hz:	47%
Extended Frequency Range:	20 ... 65 Hz:	60 %

IV Compressor Rack Design:
Rack Configurations: 2-cylinder reciprocating compressors



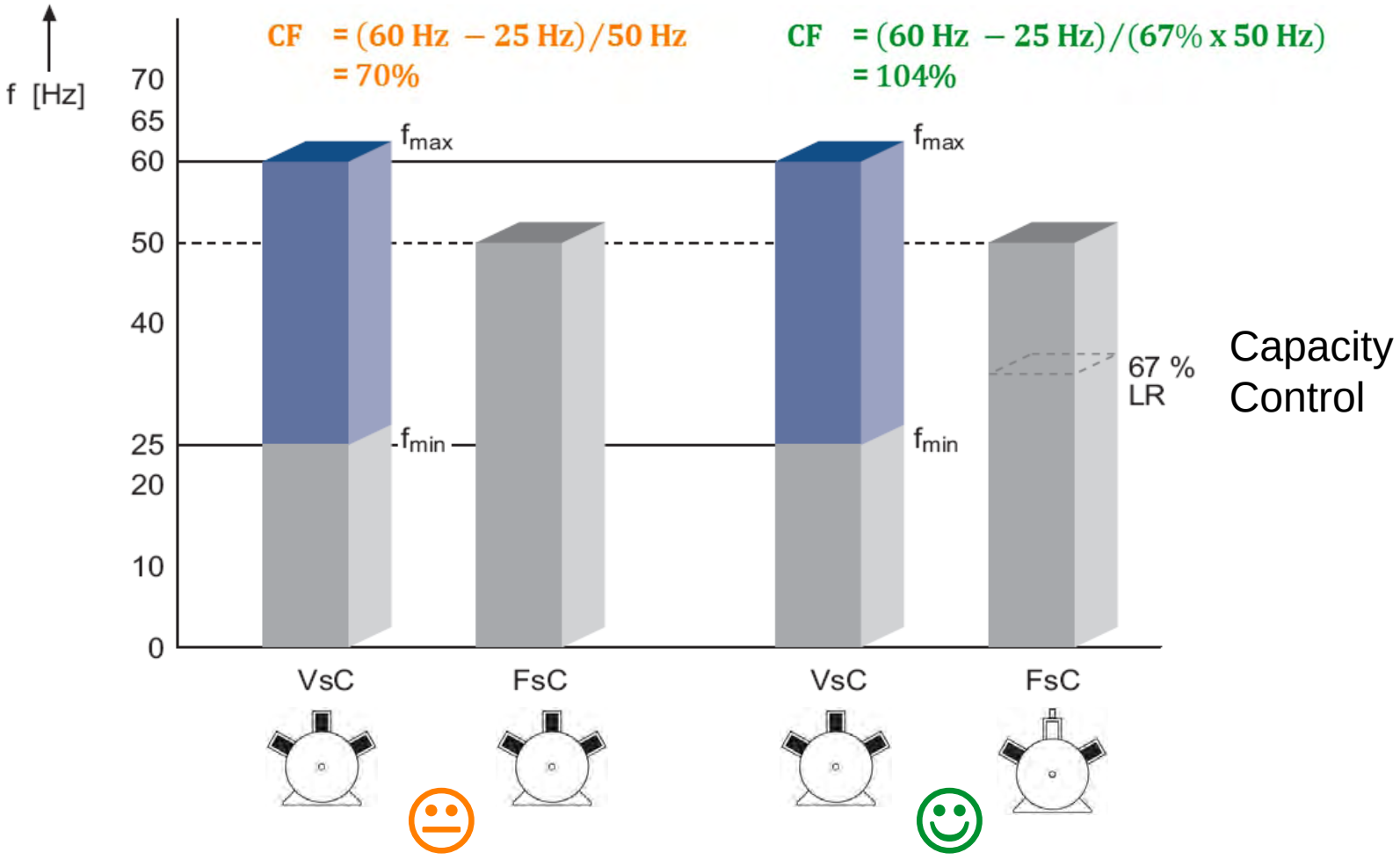
KIMO Refrigeration HVAC

IV Compressor Rack Design:
Rack Configurations: 4-cylinder reciprocating compressors



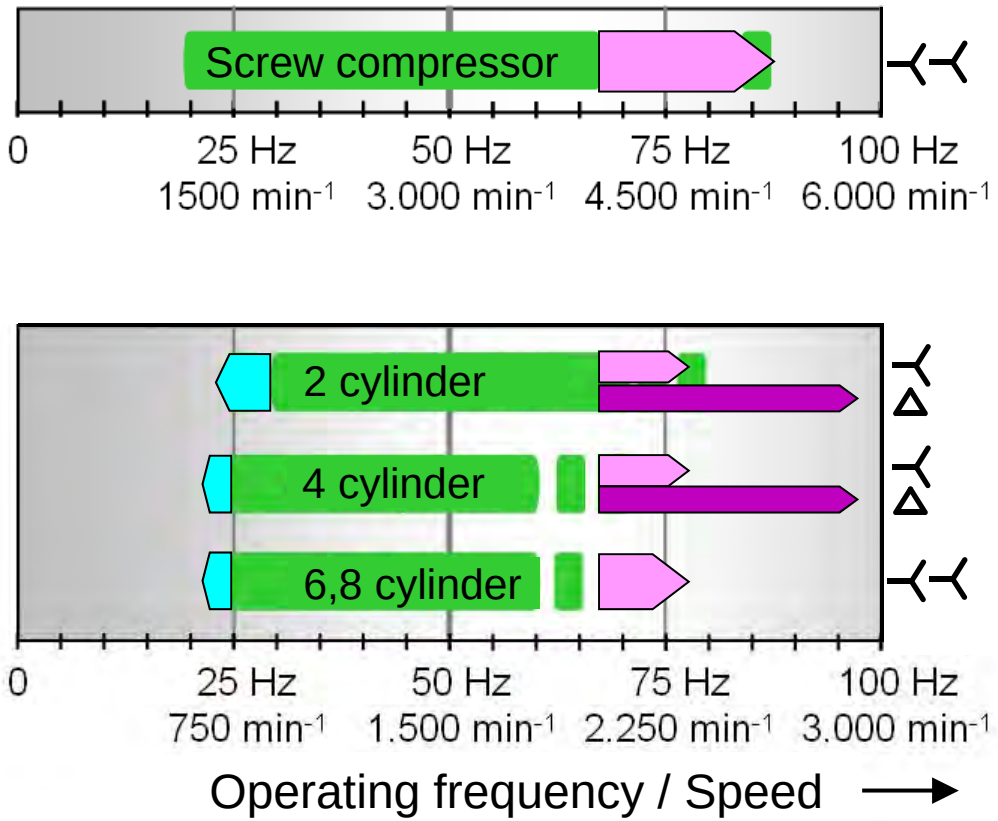
Capacity Control

IV Compressor Rack Design:
Rack Configurations: 6-cylinder reciprocating compressors



Capacity Control

IV Compressor Rack Design:
Control factor: Improvement by increasing speed range



f_{max} limit:
Automatically self-adjusting
(Intelligent Sliding Control)

f_{min} limit:
Automatically self-adjusting
(Intelligent Sliding Control)

Intelligent Sliding Control:
Based on:
Refrigerant,
p_0, p_c, t_s, t_d, M_{mot}

IV Compressor Rack Design:
Control factor: f_{max} limit (4-cylinder as an example)

Industrial frequency inverters

- HT: R404A +5 / +50 °C:
  Y: 55 Hz Δ: 87 Hz
- MT: R404A -10 / +45 °C:
  Y: 60 Hz Δ: 87 Hz

  R134a -10 / +45 °C
  Y: 60 Hz Δ: 87 Hz
- LT: R404A -35 / +40 °C:
  Y: 60 Hz Δ: 87 Hz

Inverter current rating (≈cost):
Y: 100 % Δ: 167%

Refrigeration Inverters

- HT: R404A +5 / +50 °C:
  Y: 57 Hz Δ: 87 Hz
- MT: R404A -10 / +45 °C:
  Y: **68** Hz Δ: 87 Hz

  R134a -10 / +45 °C
  Y: **75 Hz** Δ: 87 Hz
- LT: R404A -35 / +40 °C:
  Y: **75 Hz** Δ: 87 Hz

Intelligent Sliding Control:
Based on:
Refrigerant, p_0, p_c, t_s, t_d, M_{mot}

KIMO Refrigeration HVAC

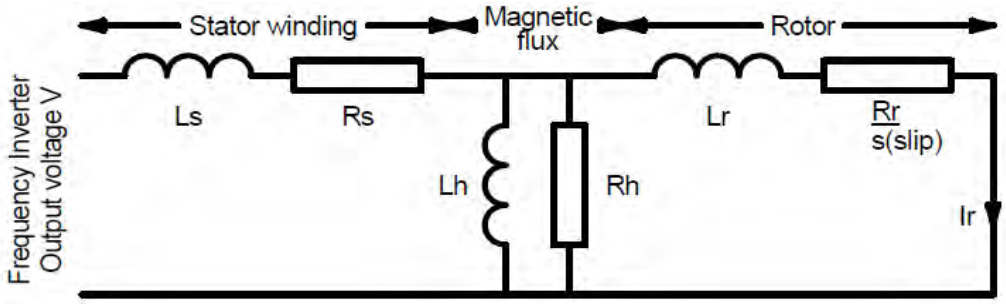
IV Compressor Rack Design:
Control factor: Estimating f_{max} limit

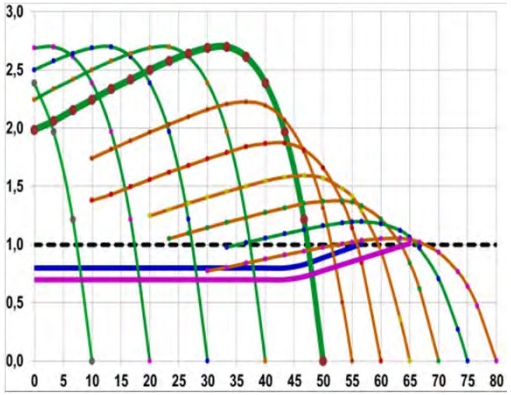
Mechanical considerations

- Oil pump
- Discharge gas temperature
- Piston velocity
- High f_{max} ➔ Better Control Factor ➔ Fewer compressor starts

Electrical Considerations

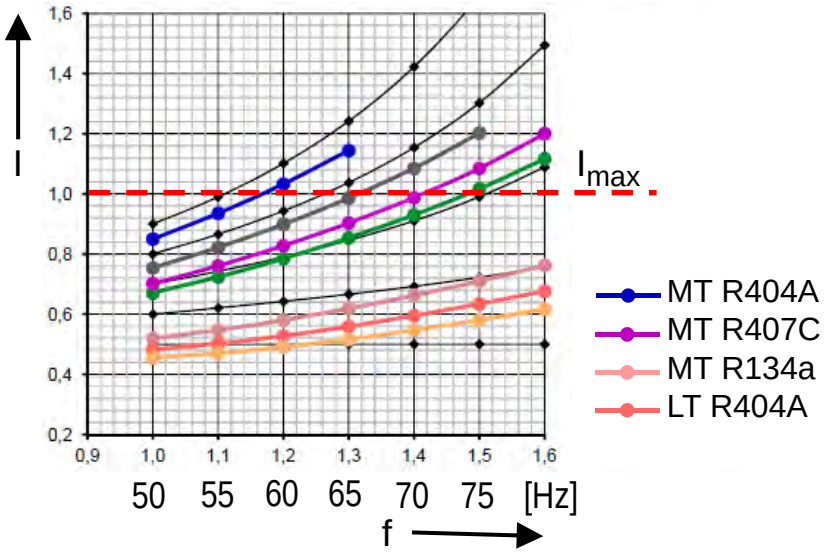
- Always consult compressor manufacturer
- Maximum motor current
- Supply voltage (Limit in field weakening)
- Use motor equivalent circuit



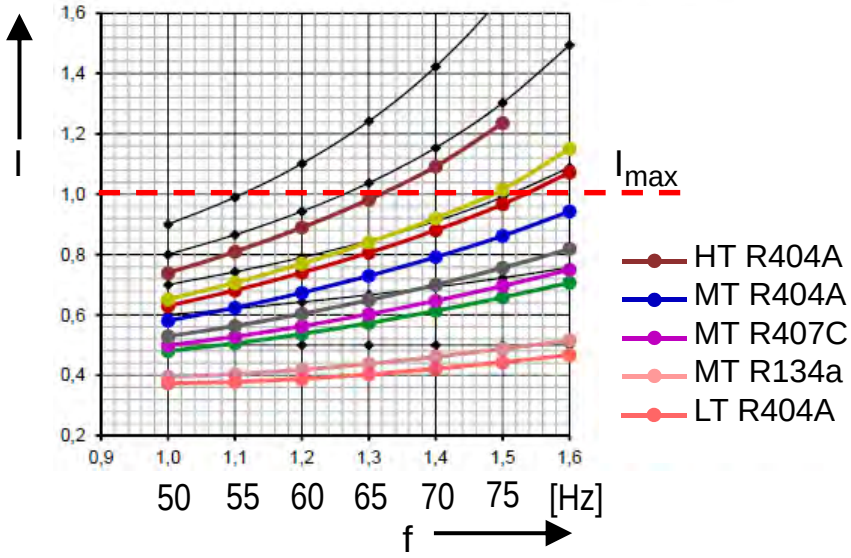


IV Compressor Rack Design:
Control factor: f_{max} limit for star connection

Small-motor compressor (example):



Large-motor compressor (example):



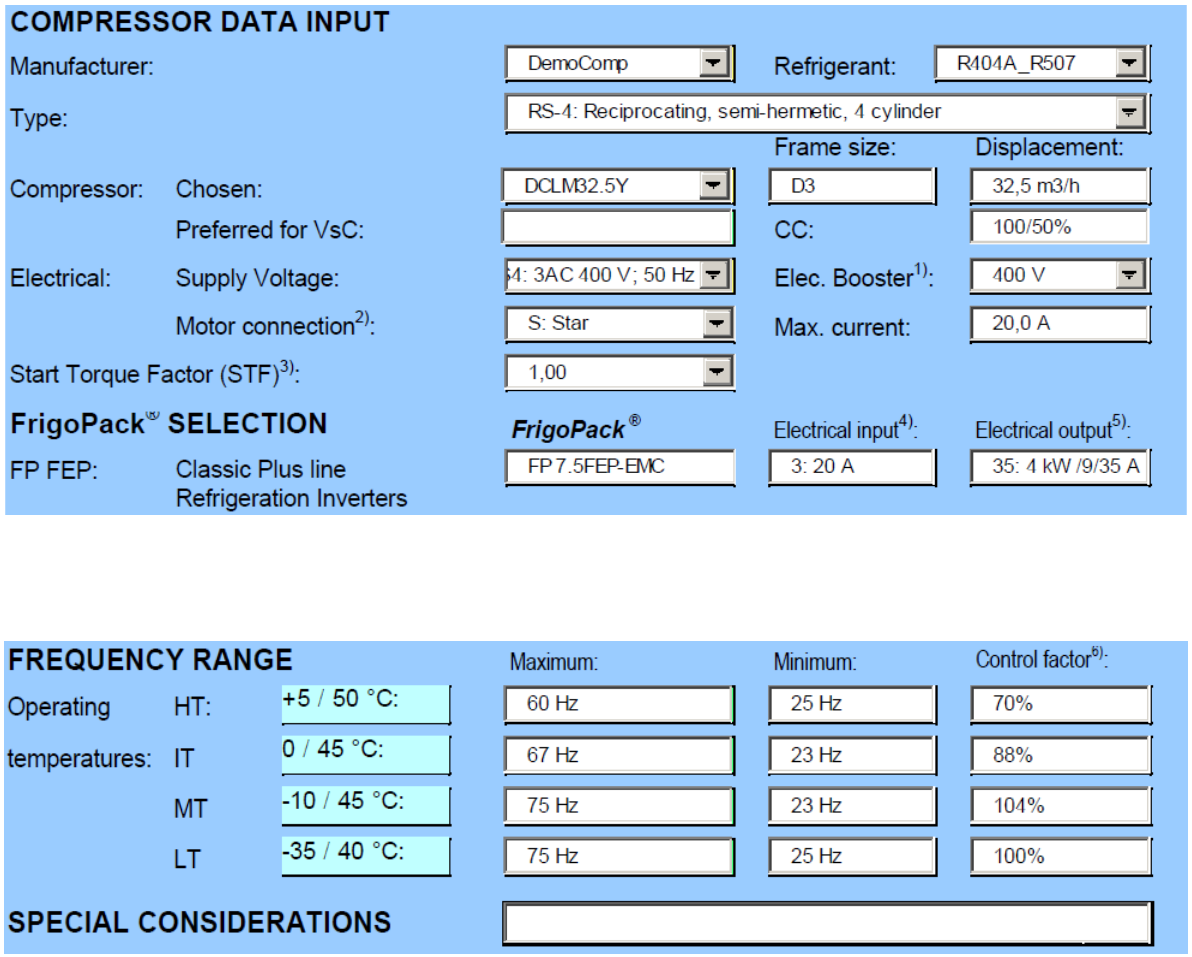
Small-motor compressor in star

MT R404A:	Not recommended		
MT R134a:	f_{max}: ...75 Hz	CF: ≈100 %	
LT R404A:	f_{max}: ...75 Hz	CF: ≈100 %	

Large-motor compressor in star

MT R404A:	f_{max}: ...68 Hz	CF: ≈ 90 %
MT R134a:	Small-motor compressor preferred	
LT R404A:	Small-motor compressor preferred	

IV Compressor Rack Design:
How can selection software be of assistance?



Input:
Refrigeration Data
Compressor selection

Electrical Data
Starting conditions

Selection:
Refrigeration Inverter +
Electrical planning data

Performance:

HT: f_{min}, f_{max}, CF
IT:
MT:
LT;

IV Examples of Refrigeration Inverter Installations
Refrigeration for Food Production

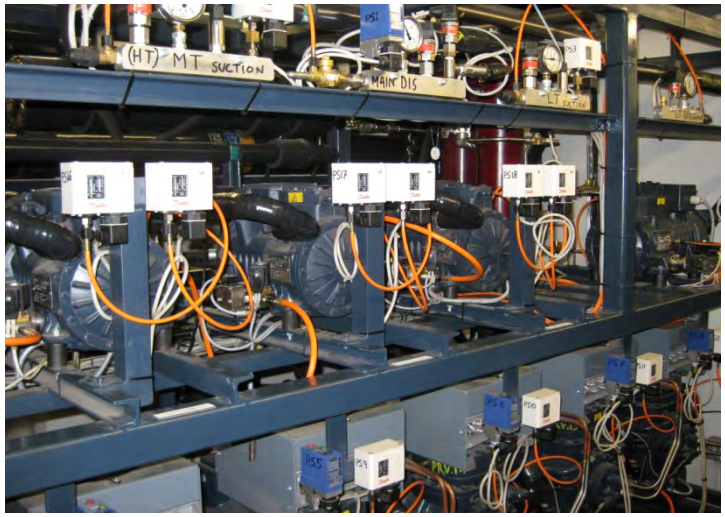
- **Low Temperature:**
  - **Variable-speed inverter Compressor**: 4 cyl.reciprocating
  - **Fixed-speed Compressors** 2 x 6 cyl.reciproc.
  - **Refrigeration inverter**
- **Medium Temperature:**
  - **Variable-speed inverter Compressor**: 6 cyl.reciprocating
  - **Fixed-speed Compressors** 2 x 6 cyl. reciproc. 100 / 67 % Capacity Control Control Factor: 120 %
  - **Refrigeration inverter**

IV Examples of Refrigeration Inverter Installations
Supermarket with R744 technology (transcritical)

- **L**ow **T**emperature:

- **M**edium **T**emperature:

- **I**ntermediate **P**ressure



Refrigeration Inverters with optimized Control Factor

IV Examples of Refrigeration Inverter Installations
Large Supermarket (R507A)

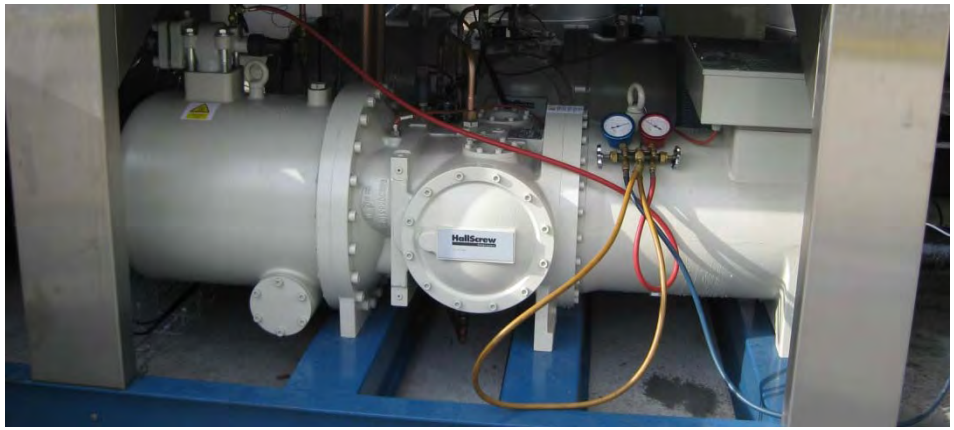
MT1: 6x compressors
MT2: 5x compressors
MT3: 4x compressors
LT: 4x compressors

All 4x Refrig. Inverters with optimized Control Factor:

	f_{min}	f_{max}	CF:
MT	23	68 Hz	90%
LT	23	70 Hz	94%

Chiller for plastic moulding machine (R407C)

C1: CHILLER FOR PLASTIC MOULDING MACHINE



Process chiller (R407C; 720 kW)
- **2x VsC: Screw Compressors**
- **2x Refrigeration Inverters:**
  - **Optimized Control Factors**
  - **Integrated energy-optimized chiller control**