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COMPUTER DRIVEN AUTOMATIC CONTROL OF THE HYBRID TWO STAGE REFRIGERATION CYCLE

WSPIERANE KOMPUTEROWO AUTOMATYCZNE STEROWANIE HYBRYDOWEGO DWUSTOPNIOWEGO UKŁADU CHŁODNICZEGO

Abstract

In the paper the method of automatic control of the two stage hybrid sorption-compression refrigeration system for different ambient conditions is presented. The main advantages of the system are its environmental friendly working fluids and waste or renewable low temperature heat source utilization. The control algorithm is designed for operation in four seasons' conditions. During cold seasons the heat from the second stage condenser, as waste heat, may be used to increase the temperature of the heat pump source. The system is composed of dependent subsystems with individual controls, however it is controlled by the computer program as master control. The issues related to the optimization of operation of the refrigeration system, taking into account the maximum usage of available renewable or waste heat sources, are discussed in the paper.

Keywords: *hybrid, refrigeration cycle, computerised control*

Streszczenie

W artykule przedstawiono metodykę automatycznego sterowania dwustopniowej adsorpcyjno-sprężarkowej kaskady chłodniczej w zależności od różnych warunków otoczenia. Główna zaleta prezentowanego systemu wynika z wykorzystania przyjaznych dla środowiska czynników chłodniczych. System wykorzystuje do pracy energię cieplną z niskotemperaturowych źródeł odnawialnych. Algorytm sterujący został przygotowany tak, aby utrzymać pracę systemu przez cały rok. Podczas okresu zimowego ciepło ze skraplacza, jako ciepło odpadowe, może zostać wykorzystane do podwyższenia temperatury źródła pompy ciepła. System zbudowany jest z zależnych od siebie podsystemów, dlatego ich praca zarządzana jest przez program komputerowy. Zostaną omówione zagadnienia związane z optymalizacją pracy systemu chłodniczego biorące pod uwagę maksymalne wykorzystanie dostępnych źródeł ciepła.

Słowa kluczowe: *hybrydowy system chłodniczy, sterowanie komputerowe*

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1. Introduction

In the Laboratory of Thermodynamics and Thermal Machines Measurements at the Cracow University of Technology the refrigerating laboratory stand has been designed and constructed [1–3]. The system is hybrid and unique since it combines the attitudes of adsorption cycle driven by a low temperature heat source, with compression low temperature stage working with CO_2 [4]. To achieve the best possible results and assure safe plant operation a specially designed control system has been designed [5].

The control system is composed of several parts for each thermodynamic subsystem. However, a master control system with programmed setups for different ambient conditions as well as refrigeration chamber requirements has been also been made.

2. Composition of the control system

A schematic diagram of the control system designed for hybrid refrigeration stand TSD [6, 7] is shown in Fig 1. ST0 – PC class computer with two displays M0 and M1, communication with measurement cards is provided through RS485, for data gathering from IPC cards the modbus protocol has been used, communication with PLC controller and expansion valve controller, further calculations on the gathered data, data storage, supervising and online graph generation [8, 9].

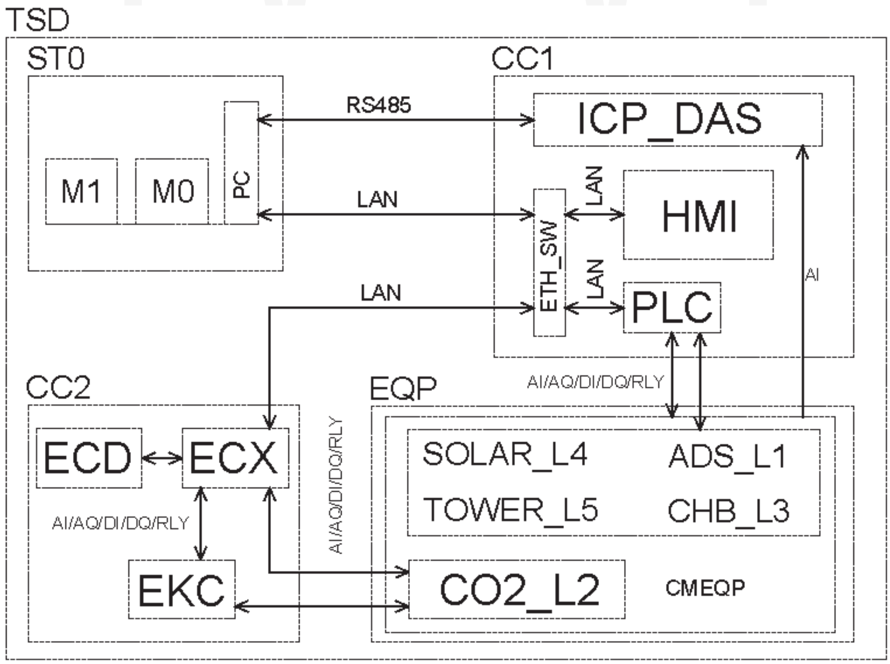

Fig. 1. Block schematics of the system

Professional software has been used, as well as software tools for PLC and HMI programming such as: SIEMENS TIA Portal V.13 STEP 7.

The software ”kaskada” for readings of the data from the IPC cards and recalculating them has been written using Visual Studio 2013 Professional. Kaskada_vi is the part written in Lab View, where the NIST REFPROP for refrigerant properties has been used. Also other software such as CoolPack, Mathcad for calculations have been used.

CC1 MAIN CASE – measurements of: temperature and pressure, mass and volume flow rates, electric power for electric devices. Also a PLC controller for the whole system is included. The main parts are:

- ICP_DAS 8 pcs. M-7017RC cards, for data acquisition, this as a whole measuring system which gives 64 analog input signals of which 52 are used at this development stage.
- PLC SIEMENS S7 CPU 1217C controller with Ethernet/PROFINET interface and CM 1241 RS485 for communication ports. The PLC is equipped with 14 x DI digital input, 10 x DQ digital output signals, 2 x AI analog input, 2 x AQ analog output signals, to PLC are connected eight expansion modules with sum of: 40 x AI analog inputs, 8 x AQ analog outputs, 16 x RLY relay switched outputs.
- HMI KTP700 Basic PN operator panel with Ethernet/PROFINET interface for communication.

EQP subsystems of the refrigeration stand:

- SOLAR_L4 solar subsystem presented in Fig. 2: Temperature measurements, t_{IN1}, t_{IN2}, t_{IN3}, t_{IN4}, t_{OUT1}, t_{OUT2}, t_{OUT3}, t_{OUT4}, Pressure measurements p_{IN}, p_{OUT}. Mass flow measurements m_1. Liquid pump – PCS2 with the electric power measurement.

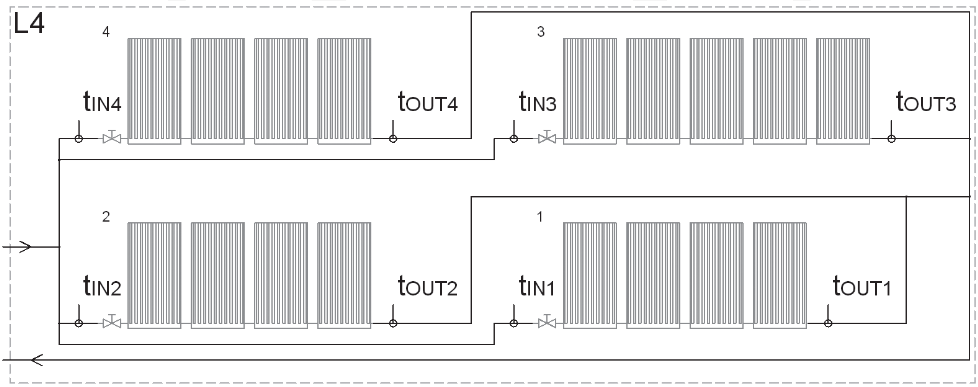

Fig. 2. SOLAR_L4 solar subsystem

- CHB_L3 heat container presented in Fig. 3: Temperature measurements, t_{z1}, t_{z2}, t_{AKU} in a liquid container. Circulating pumps, P1, P2. Electronic valves, ZV_1, ZV_6.
- ADS_L1 adsorber presented in Fig. 4: Temperature measurements, t_1, t_2, t_3, t_4, $t_{4'SP}$, $t_{5'SP}$, t_5, t_6. Mass flow measurements, m_{1AD}, m_2, $m_{3.}$ Circulating pumps: PCS1, PCS2, PCS3, PCS4. Adsorber with electric power measurement.

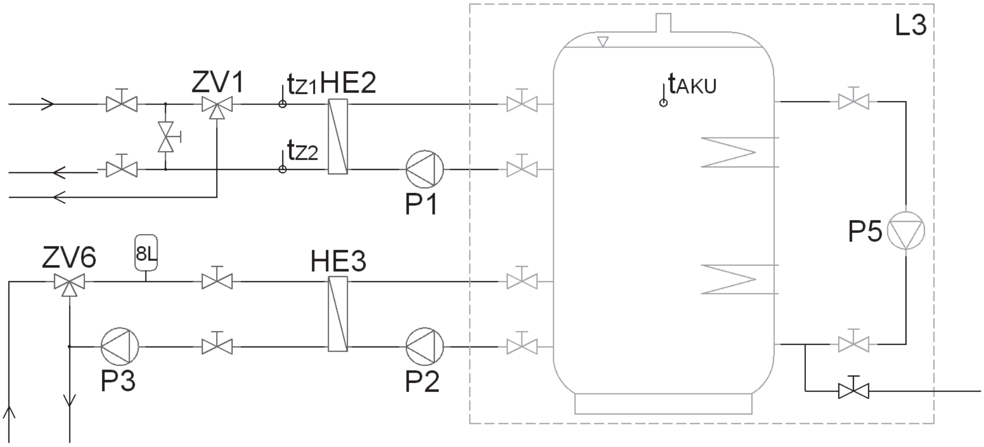

Fig. 3. CHB_L3 heat storage subsystem

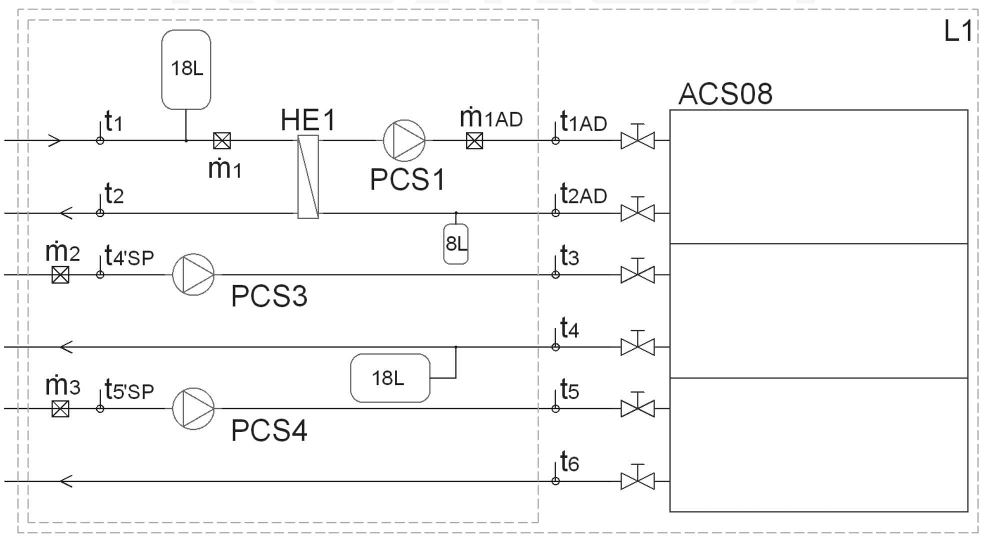

Fig. 4. ADS_L1 adsorber subsystem

- TOWER_L5 water sprayed cooling tower: Temperature measurements, $t_{3'}$, $t_{4'}$. Mass flow measurements. Fan supply and a water spraying pump with the electric power measurement.
- CMEQP common part of the acting elements: servomotors for valves, circulating pumps.
- ETH_SW network switch LAN 1000/100/10 Mbit/s.

CC2 subsystem case CO_2 consists of an independent controller EKC with an independent safety subsystem, an overheating controller for expansion valve ECX. This controller has been built into awebpage where work parameters can be changed using a web page browser, ECD controller parameters display.

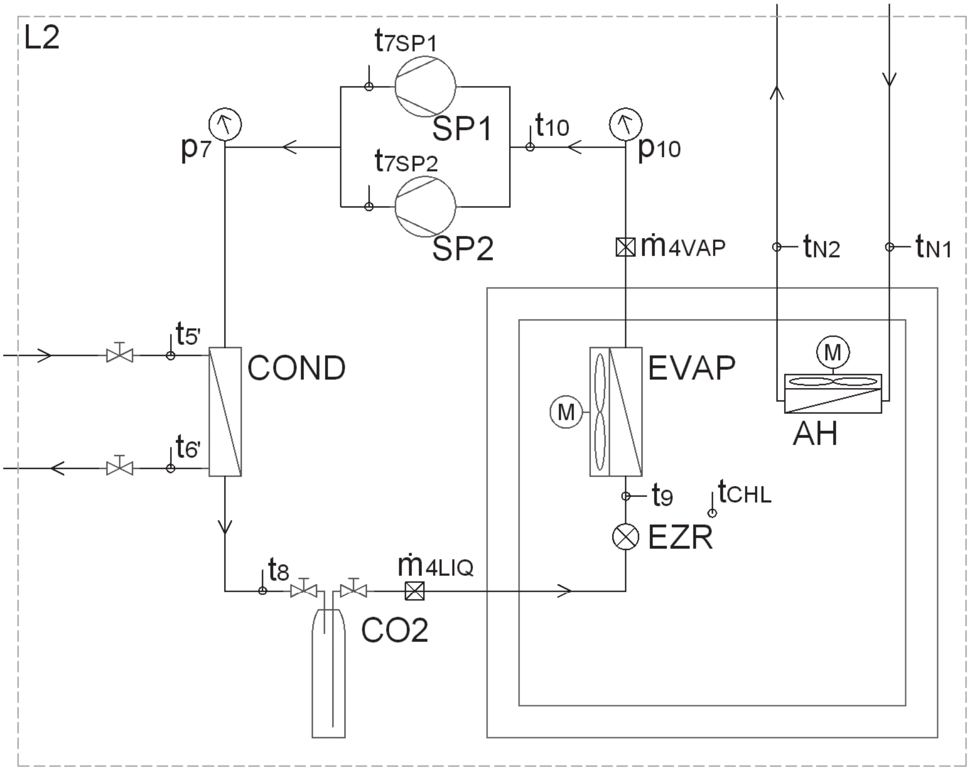

Fig. 5. CO2_L2 compression CO_2 subsystem

CO2_L2 compression system CO_2 presented in Fig. 5: Temperature measurements, $t_{5'}$, $t_{6'}$, t_{7SP1}, t_{7SP2}, t_8, t_9, t_{10}, t_{CHL}, t_{N1}, t_{N2}. Pressure measurements, p_7, p_{10}. Mass flow measurements: m_{4LIQ}, m_{4VAP}. Compressors: SP1, SP2 with the electric power measurement. Frequency inverter. Flow through heater used for simulation of the heat load in the refrigeration chamber.

3. Algorithms and optimization

The system has several operation setups for each subsystem.

Subsystem ADS_L1 – the adsorber operation has four main regimes:

1. Summer day operation (SDW) regime when the input temperature from the heat source exceeds 65[°C], and the ambient air temperature is higher than 13[°C]. Then the adsorption subsystem works in the cooling mode. Since the outlet cooling temperature from the

adsorber is a function of cooling load, it is sufficient to leave the cycle for the lowest possible cooling temperature.This self-adjustment function of the adsorption unit allows to achieve the lowest possible condensing temperature, reducing total energy consumption. This regime works until two above mentioned temperatures used as control functions are be exceeded;

2. Summer night operation (SNW), the adsorber work is no longer possible when heat source temperature decreases below 65[°C], then the adsorption system has to be stopped, and only then the cooling tower is used to cool down the CO_2 condenser;
3. Heat pump operation (HPW): this option is used when the ambient air temperature is lower than 13[°C]. Then the adsorber may be used separately as a heat pump for waste and ambient heat and use the heat collector as HT source, while the MT (medium temperature heat) is used for domestic/company heating. In this case CO_2 cycle condenser is cooled down directly from the cooling tower;
4. Additional heater operation (AHW). The temperature of the heat source is below 65[°C] and the requirements for condenser cooling are higher than the cooling tower can give. This may be the case only in special ambient conditions with very high relative air humidity and high temperature when no waste or solar heat source is available.

Subsystem CO2_L2 – compression cycle CO_2:

1. The cooling requirements for CO_2 condenser may in some cases be limited, and additional cooling power will be required. In this case there are two possibilities: the control signal is released to run the AHW program in the L1 subsystem, in the meanwhile reducing the compressor power;
2. The frequency inverter mounted on one of the cascade controlled compressors, allows to control the refrigeration power with the relationship to current chamber load. The compression cycle works using variable load control which is more efficient than a standard on/off system.

Subsystem CHB_L3, SOLAR_L4, TOWER_L5. The heat container subsystem is simple in operation. It has electric heater with an on/off system only for the L1 AHW mode. Also the valves ZV and pumps have to work in harmony with other subsystem modes.

1. Mode SAC – the solar heat accumulation is controlled using temperature readings. Once the temperature reading is higher than the set point, the PCS2 pump starts and works until the outlet temperature from solar collectors exceeds the temperature in heat container for 15[K]. Then the P1 pump starts and the heat container load starts. This accumulation goes on until the glycol temperature in the solar circuit lowers below the container's temperature plus 2–3[K]. In the case of fast solar collectors temperature decreases the PCS2 pump is off. In the case of full heat container load (95[°C] achieved) the mode SAC changes to the mode SWS. The pump's efficiency is also changed based on temperature readings and heat flux;
2. Mode SW solar work– the heat accumulator is fully loaded (95[°C]), then P1 pump goes off, if the L1 subsystem is on the SDW mode the glycol directly heats the adsorber. In the case when the solar temperature is too high or the subsystem L1 is off, the mode SW changes into the SWS mode. Registered work in this mode is presented in Fig. 6;
3. SWS mode – solar waste mode. This is the case when no heat source is needed (L1 is not operating, accumulator is full) and there is a considerable amount of solar radiation and the temperature readings in the solar subsystem exceed the points set (about 100[°C]), then the pump PCS2 has to be put into operation and all the heat goes to the cooling tower.

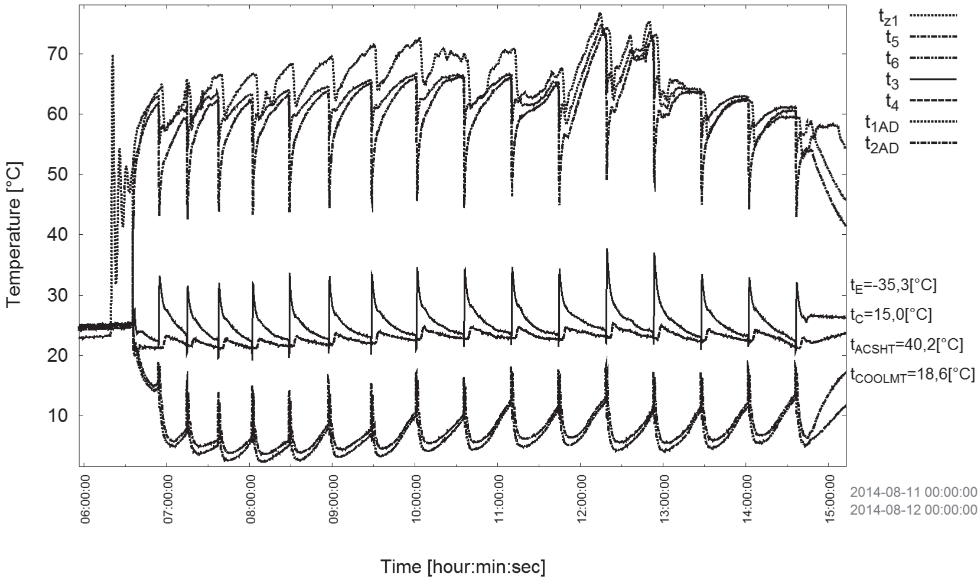

Fig. 6. Graph of temperatures for ADS_L1 with CO2_L2 for SW regime

In Fig. 6. A raph of temperatures measured during the system operation in the SW mode is shown. The oscillation of the values is the result of the adsorber's cyclic work. However, this does not influence the LT stage condenser operation. The main optimization criteria of working algorithms of the presented system are the minimum of electric power needed and the maximum possible usage of waste or renewable heat sources. Algorithms presented above are still under development and modification. Also self-adjustment of temperatures and heat fluxes levels for switching between regimes are tested. The first level of algorithms is based on temperatures, the second level on heat fluxes and cooling demand in a steady state, the third level on heat fluxes in unsteady state, the fourth level on prediction of availability of heat sources based on the actual state of the system and the day of year (calendar, season) as well as the actual time and previously recorded data. This has to be done to ensure high quality of operation without frequent unnecessary switching between the modes.

5. Conclusions

In this paper the new compression-adsorption hybrid cycle computer driven control system has been shown. The system has been designed, constructed and investigated in the Laboratory of Thermodynamics and Thermal Machines Measurements at the Cracow University of Technology (Politechnika Krakowska).

The system needs to run for different ambient weather conditions, so all setups need to be tested for more than one year. Besides, the control system is very complex so the optimization of its operation is still under development.

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